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FOREWORD

Presented number of Silesian University of Technology. Scientific Papers. Organization and Management Series. Contemporary management. The number consists of 36 papers.

The papers presented in the number concentrate on many topics connected with organization and management. There are in the number papers about: social participation; artificial intelligence in management; internationalization in business; marketing; purchase preferences; strategic management; logistics; innovativeness; corporate social responsibility; quality management; economics; public management; environmental management; virtual reality; manufacturing process management; Industry 5.0; leadership; entrepreneurial management; human resources management and security management.

Radosław Wolniak

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A STUDY ON THE UNDERSTANDING OF SOCIAL PARTICIPATION AMONG EMPLOYEES OF SELECTED CITY OFFICES

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Purpose: The article aims to examine the perception of social participation among employees of city offices in Silesia. The analysis covers the understanding of this phenomenon, the evaluation of the involvement of city authorities, identified barriers, and suggestions for improvements.
Design/methodology/approach: The study employs the survey method. A questionnaire consisting of 16 questions was addressed to employees of city offices in two cities with powiat status. Both quantitative and qualitative data obtained from closed-ended and open-ended questions were analyzed.
Findings: The study revealed a diverse perception of social participation among city office employees. Significant differences were noted in the assessment of the level of involvement of the authorities and identified barriers. The results indicate the need to strengthen the dialogue between the office and residents, and the necessity of education in the field of participation.
Research limitations/implications: The study was conducted on a limited sample of two cities, which may affect the generalizability of the results. Future research could cover a larger number of cities and include the perspective of residents.
Practical implications: The results of the study can serve as a basis for developing strategies to increase social participation in cities. It is advisable to introduce training for officials and develop tools for communication with residents.
Social implications: Increasing social participation can contribute to the strengthening of local democracy, increased citizen trust in authorities, and improvement of the quality of life in cities.
Originality/value: The article brings a new perspective on the perception of social participation by employees of city offices in the context of Smart Cities. It presents empirical data on barriers and opportunities for improvement that can be used in practice. The article is addressed to public administration employees, researchers, and all those interested in the development of civic participation.
Keywords: social participation, city office, smart city.
Category of the paper: Research article.

1. Introduction

The role of citizens in democracy goes beyond participation in elections. Their active participation in city governance is crucial to responsive public policy. Initiatives such as community councils and participatory budgets illustrate that involving residents in decision-making can lead to more effective and equitable solutions to local problems. Therefore, being able to express opinions and influence government decisions is an important element in building a strong civil society (Fung & Wright, 2001). Understanding what public participation is and what forms it takes is crucial not only from the perspective of citizens, but also from the perspective of public administration employees, who play an important role in its initiation and implementation.

Emphasizing the importance of active citizen participation in city management, it is worth taking a closer look at the different levels of this engagement. One of the key models that systematizes these levels is Sherry Arnstein's "Ladder of Citizen Participation". This model presents eight rungs, illustrating the spectrum of social participation, from apparent involvement to real citizen power in decision-making processes. The two lowest rungs of the ladder are "Nonparticipation". This includes manipulation, where citizens are merely used to support decisions already made by the authorities, without any real influence, and therapy, the goal of which is to "cure" or "convince" citizens to accept existing plans, rather than genuinely involve them in the decision-making process. The next three rungs represent "Degrees of Tokenism", where citizens are listened to, but their voice does not necessarily translate into real power: informing, where citizens are informed about plans and decisions, but without the possibility of actively contributing opinions; consultation, where opinions are gathered, but there is no guarantee that they will be taken into account; and placation, where a certain level of representation is illusory and does not lead to a genuine sharing of power. Only the three highest rungs of Arnstein's ladder signify "Degrees of Citizen Power" and true participation: partnership, where authorities and citizens jointly plan and decide, sharing responsibility; delegated power, where citizens receive the majority of decision-making powers; and citizen control, where citizens have full control over the decision-making and management process (Arnstein, 1969).

Although Arnstein's ladder model simplifies complex power relations, it provides a valuable tool for analyzing and understanding different levels of social engagement, which is particularly important in the context of the Smart City. In smart cities, striving to use technology to improve quality of life and management efficiency, authentic and effective citizen participation, going beyond mere information or consultation, is crucial for creating solutions that meet the real needs of residents and building trust in new technologies and urban systems (Cardullo, Kitchin, 2019). Therefore, this paper focuses on examining how these different levels of participation

are understood by employees of selected city offices in the context of implementing the Smart City idea

The smart city concept is defined as an urban space in which advanced technological infrastructure is instrumental in social and economic initiatives (Eremia, Toma, Sanduleac, 2017). The overarching goal of these initiatives is to stimulate economic growth, increase efficiency in the disposition of urban resources, and build and strengthen social capital. According to another perspective, the key determinants of a smart city are also the level of education of its residents, the accumulated human and social capital, and the state of the environment (Guerrero-Pérez, Huerta, González, López, 2013).

In the context of building smart cities that focus on innovation and improving the quality of life of residents, active citizen involvement is seen as one of the key elements. This involvement is largely shaped by the attitudes and knowledge of government employees. Integrating these perspectives, the concept of "Smart City" encompasses a wide spectrum of activities implemented in urban space, including raising the digital competence of residents, creating an environment conducive to the IT sector, implementing innovations in transportation, developing ICT infrastructure, realizing sustainable development and implementing modern forms of communication between local government and citizens (Aurigi, 2005).

The various forms of citizen involvement presented here provide the background for an analysis of the perception of public participation among city government employees who interact with them on a daily basis. There are many forms of citizen involvement in city management, from traditional elections and referendums to more interactive ones. Classical public consultations gather opinions, while direct actions and administrative proceedings give greater influence. In the urban context, citizen budgets, community councils and citizen initiatives are popular. These various instruments can be systematized according to the flow of information and interaction between authorities and residents. From one-way communication to active dialogue, the effectiveness of each form of engagement needs to be evaluated differently (Rowe, Frewer, 2005).

Public consultation is a formalized, interactive process initiated and moderated by government entities. As part of this process, a public institution invites a broad spectrum of stakeholders - including both the general public and identified target groups - to provide their comments, opinions and proposals with regard to proposed normative acts, strategic public policy documents or significant problems of a social, economic or spatial nature (Choi, Wong, 2023).

The civic budget, also known as the participatory budget, is a mechanism that enables residents to actively participate in deciding on the allocation of a portion of public funds for specific projects and initiatives implemented in their community. This process aims to increase the efficiency of public finance management by better aligning expenditures with the real needs and expectations of the local community. By involving citizens in the decision-making process, the participatory budget contributes to building mutual trust between residents and local

authorities, strengthening the sense of civic control over the spending of public money. A key element of the civic budget is enabling residents to submit their own project proposals, which are then evaluated for feasibility and compliance with local development strategies. In the next stage, citizens have the opportunity to vote on selected projects, and those that receive the greatest support are implemented within a separate part of the city or municipality budget (Putri, Trisnaningsih, 2024).

Considering the key role of social participation in effective city management, especially in the context of the development of the Smart City idea, this article addresses a gap in the literature by focusing on understanding the perception of social participation among public administration employees in selected City Offices in Silesia. Specifically, this paper breaks down how city office employees define participation, what elements of this process they consider most important, how they assess the involvement of authorities in participatory initiatives, what barriers they perceive, and what actions they suggest to strengthen citizen participation in shaping smart cities, a perspective often overlooked in Smart City research.

2. Methods

In this article, which aims to understand the perception of social participation among public administration employees in selected powiat cities of the Silesian Voivodeship, a survey was used as the primary research method. The survey is a commonly used tool in social research, enabling the systematic collection of data on respondents' opinions, attitudes, and experiences on a specific topic (Babbie, 2010). This method was considered appropriate due to the ability to reach a relatively large group of employees and obtain standardized answers, which facilitates subsequent comparative analysis. The survey questionnaire used a combination of closed-ended and semi-open (hybrid) questions. Closed-ended questions were characterized by predefined answer options, which allowed for quantitative data analysis. In turn, semi-open questions combined the possibility of selecting ready-made answers with space for additional respondent commentary, allowing for richer qualitative data (Łobucki, 2007). The use of both types of questions allowed for a comprehensive examination of respondents' perceptions.

The survey questionnaire, consisting of sixteen questions, was designed to explore key aspects of the perception of social participation by public administration employees in cities with over 100,000 inhabitants. The study examined, among other things, their understanding and perception of social participation, the assessment of the current involvement of city authorities, identified barriers and opportunities for improvement, as well as the perceived benefits of its development. The survey also covered issues related to awareness of support in this area, employees' own initiative and assessment of their influence, overall satisfaction, as well as suggestions for changes and potential own actions. Additionally, demographic data

of respondents were collected in order to analyze potential differences in perception. The research sample included public administration employees from two cities with powiat status with over 100,000 inhabitants in the Silesian Voivodeship. A total of 108 respondents participated in the study (36 from City Office A and 72 from City Office B). The respondents included representatives of various levels of administration. Demographic data on age, education, gender, and length of service were also collected.

3. Results

In accordance with the procedure described in the methodology section, this part of the article will present the quantitative results obtained from surveys conducted among employees of City Office A (N = 36) and City Office B (N = 72). These data, collected using a questionnaire consisting of 16 questions, will be presented in the form of tables and graphs illustrating the distribution of answers to individual questions in both studied groups. The aim of the presentation is to show the perceptions of employees in key areas related to social participation in the context of Smart Cities.

Table 1.
Sociodemographic Data of Respondents: Length of Service Distribution

Sociodemographic data of respondents	**CO A**	**CO B**
Less than a year	8%	4%
1-5 years	11%	24%
6-10 years	22%	14%
11-15 years	33%	13%
16 years and over	25%	46%

Source: own elaboration.

Table 1 shows the distribution of respondents' length of service in both surveyed cities. In CO A, the largest group consists of employees with 11-15 years of service (33%), while in CO B, employees with 16 years or more of service dominate (46%). Differences are also visible in the percentage of employees with shorter service (less than 5 years), which is higher in CO B (28%) than in CO A (19%). These differences in the structure of length of service may potentially affect the perception and experiences related to social participation in both offices".

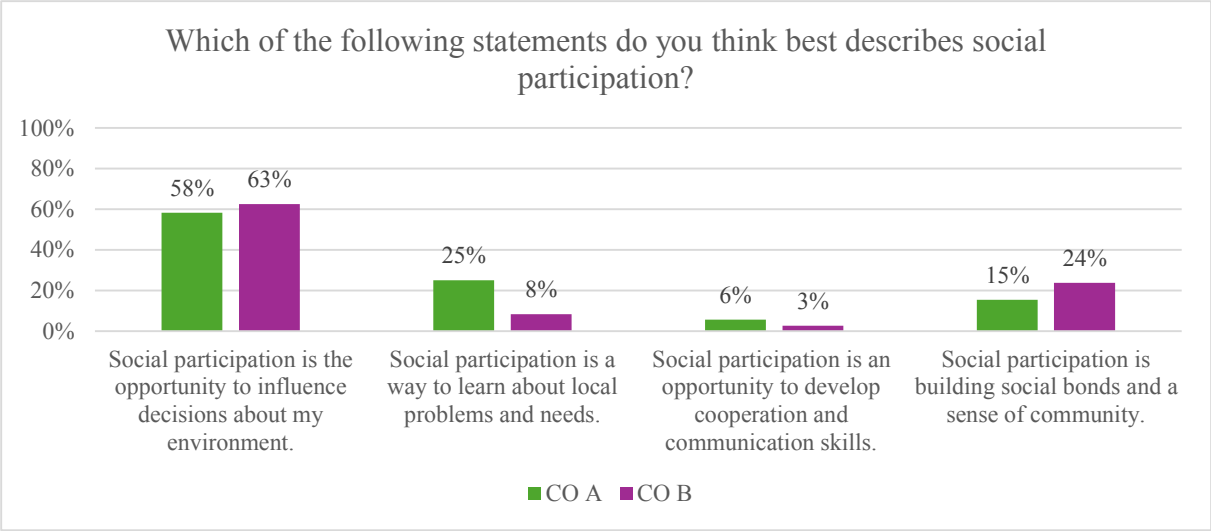

Figure 1. Comparison of Preferred Definitions of Social Participation among Employees of City Offices A and B.

Source: own elaboration.

Analysis of Figure 1 shows that in both cities, the perception of participation as the possibility of influencing decisions prevails (CO A 58%, CO B 63%). In City Office A, the second place is occupied by the definition related to understanding problems (25%), and in CO B, with building relationships (24%). Developing cooperation skills is perceived as the least important. The similarity in the dominant definition indicates a common understanding of the key aspect of participation, however, differences in further preferences may reflect different local emphases in the approach to participation.

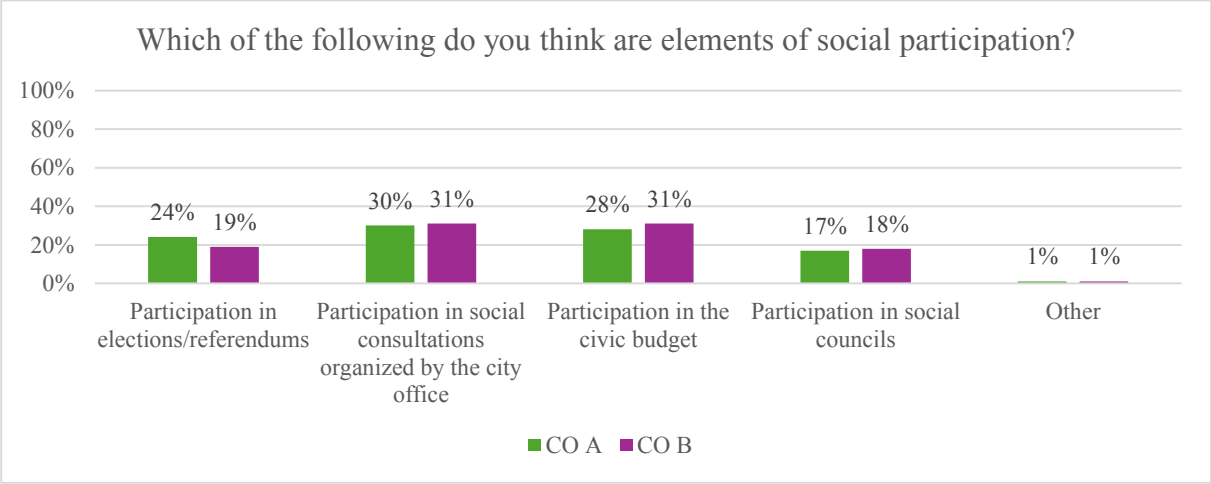

Figure 2. Comparison of perceived elements of public participation among City Offices A and B employees (multiple indications).

Source: own elaboration.

Figure 2 shows that employees in both cities most often identify participation in social consultations organized by the city office (CO A 30%, CO B 31%) and participation in the civic budget (CO A 28%, CO B 31%) as key elements of social participation. The chart indicates a similar importance of these forms of engagement in both locations. The similarity in the frequency of indications for consultations and the civic budget, shown in the chart, suggests that these forms of participation are well recognized and valued by public administration employees in both cities. Slightly lower indications for participation in elections and social councils may indicate a different perception of their role in the spectrum of social participation from the perspective of officials.

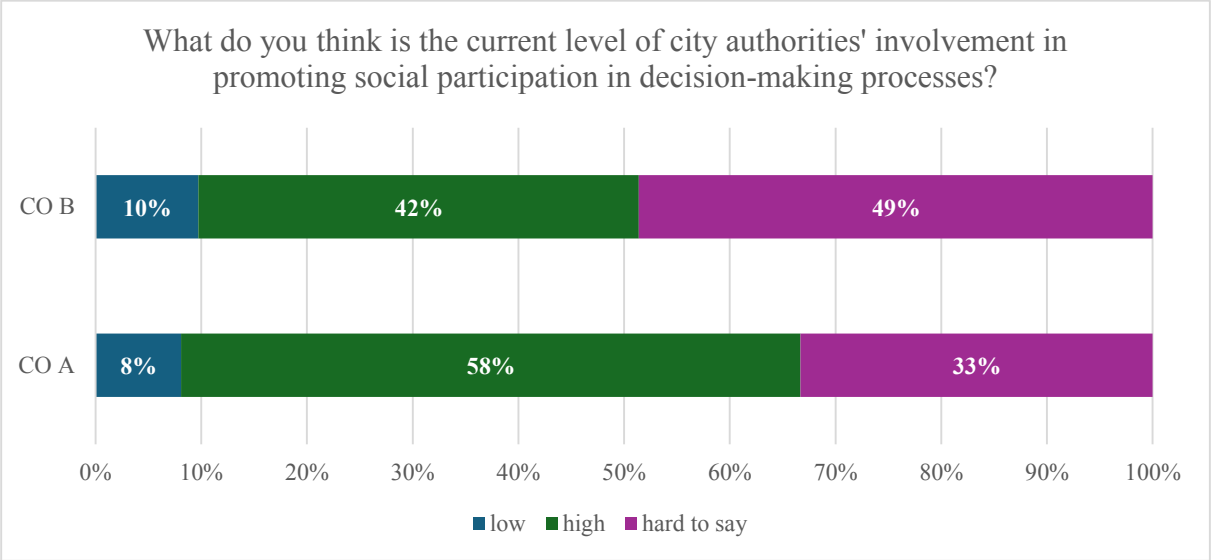

Figure 3. Assessment of City Authorities' Involvement in Promoting Social Participation by City Office A and B Employees.

Source: own elaboration.

Analysis of Figure 3 reveals clear differences in the assessment of city authorities' involvement in promoting social participation between employees from city offices A and B. In CO A, the vast majority of respondents (58%) perceive this level as high. In contrast, in CO B, the largest group of employees (49%) chose the answer "hard to say", and the percentage assessing the involvement as high is much lower (42%). The dominant assessment of the level of involvement as high in CO A, in contrast to the prevailing uncertainty in CO B, visible in the chart, suggests potential differences in the intensity or visibility of activities promoting participation in both cities from the perspective of their officials. The larger group of employees in CO B for whom the assessment of the level of involvement is difficult may indicate a need for better internal communication or less exposure of employees to participatory initiatives in this city.

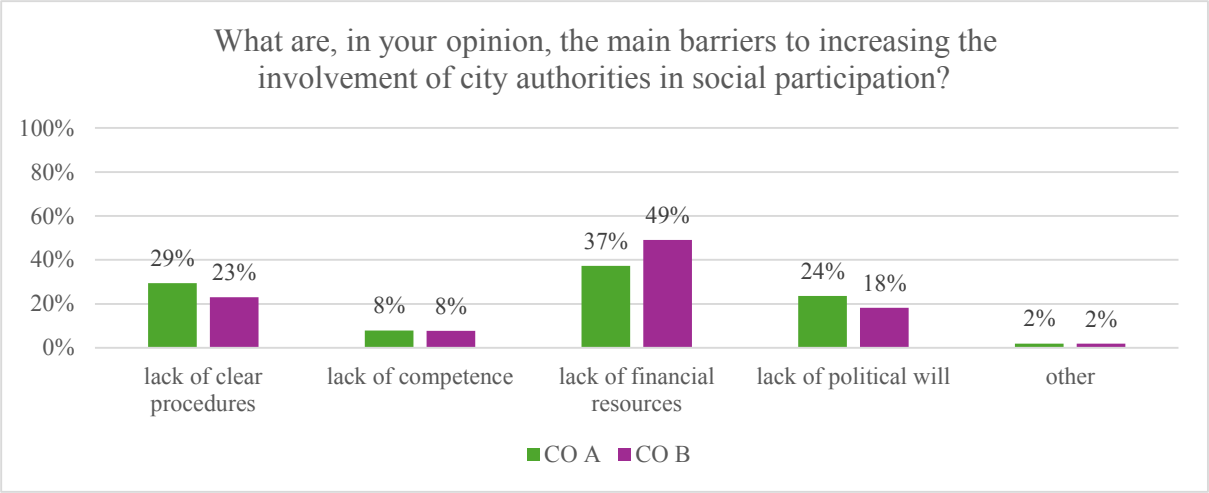

Figure 4. Key Barriers Hindering City Authorities' Engagement in Promoting Social Participation, as Indicated by City Office A and B Employees (multiple indications).

Source: own elaboration.

Analysis of Figure 4 shows that employees in both cities identify a lack of financial resources as one of the main barriers to increasing the involvement of authorities in social participation (CO A 37%, CO B 49%). The chart reveals that this barrier is particularly strongly perceived in CO B. The dominant indication of a lack of financial resources, shown in the chart, suggests that budget constraints are seen as a major obstacle in developing participatory initiatives. The lack of clear procedures is also significant, indicating the need for systemic regulations in the area of participation. Differences in the perception of a lack of political will may reflect different local political contexts and priorities.

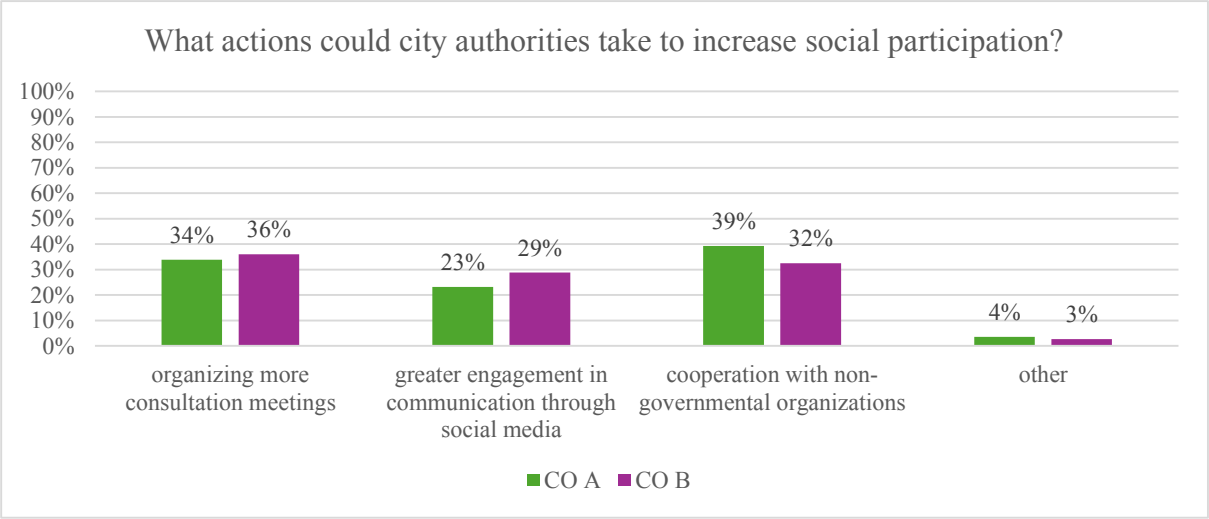

Figure 5. Suggested Actions by City Authorities to Enhance Social Participation, as Indicated by City Office A and B Employees (multiple indications).

Source: own elaboration.

Analysis of Figure 5 shows that employees in both cities most often suggest cooperation with non-governmental organizations as an action that city authorities could take to increase social participation (CO A 39%, CO B 32%). The chart also indicates organizing more consultation meetings as an important suggestion in both cities (CO A 34%, CO B 36%). Greater involvement in communication through social media is also mentioned as a potential action (CO A 23%, CO B 29%). The "Other" response received marginal support in both locations, as seen in the chart. The dominant indication of cooperation with non-governmental organizations, shown in the chart, suggests that employees see great potential in partnering with the social sector in engaging residents. Increasing the number of consultation meetings and more active use of social media in communication with residents are also important in order to increase participation.

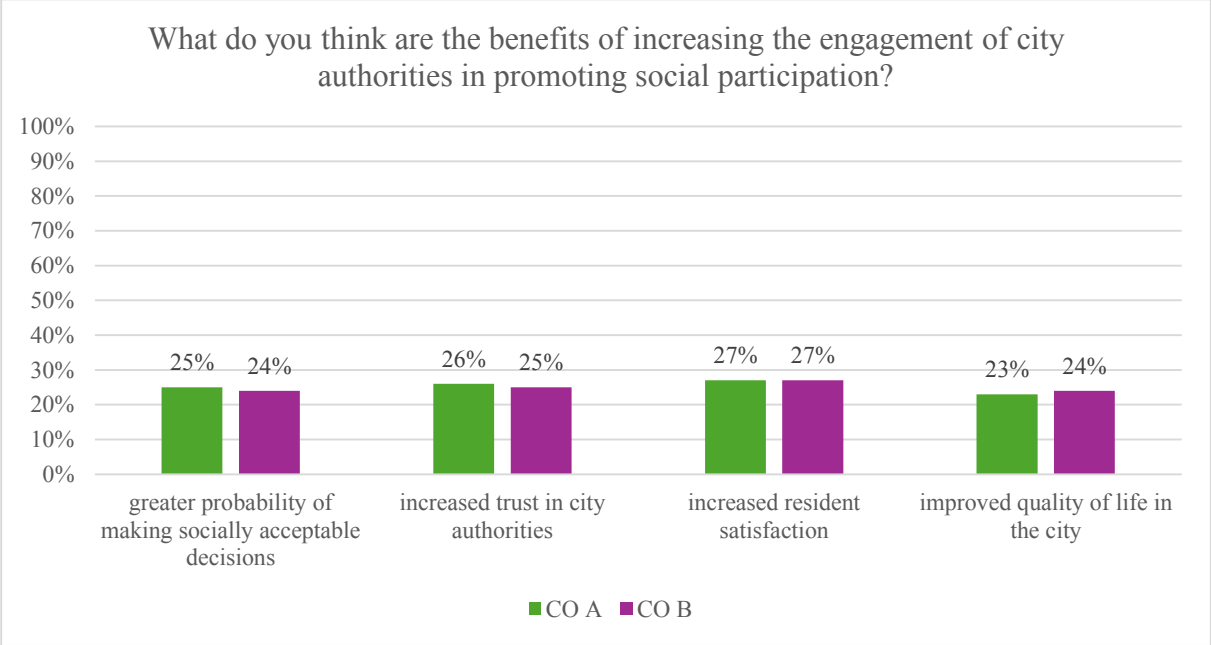

Figure 6. Perceived Benefits of Enhanced Engagement of City Authorities in Promoting Social Participation, as Indicated by City Office A and B Employees (multiple indications).

Source: own elaboration.

Analysis of Figure 6 shows that employees in both cities identify the key benefits associated with increased engagement of city authorities in promoting social participation to a similar extent. The most frequently mentioned benefit in both locations is increased resident satisfaction (CO A 27%, CO B 27%). The similarity in the distribution of indications for individual benefits, visible in the chart, suggests that public administration employees in both cities have a similar belief about the positive effects of increased social engagement. The dominant indications for increased resident satisfaction and trust emphasize the importance of participation in building positive relationships between authorities and the local community.

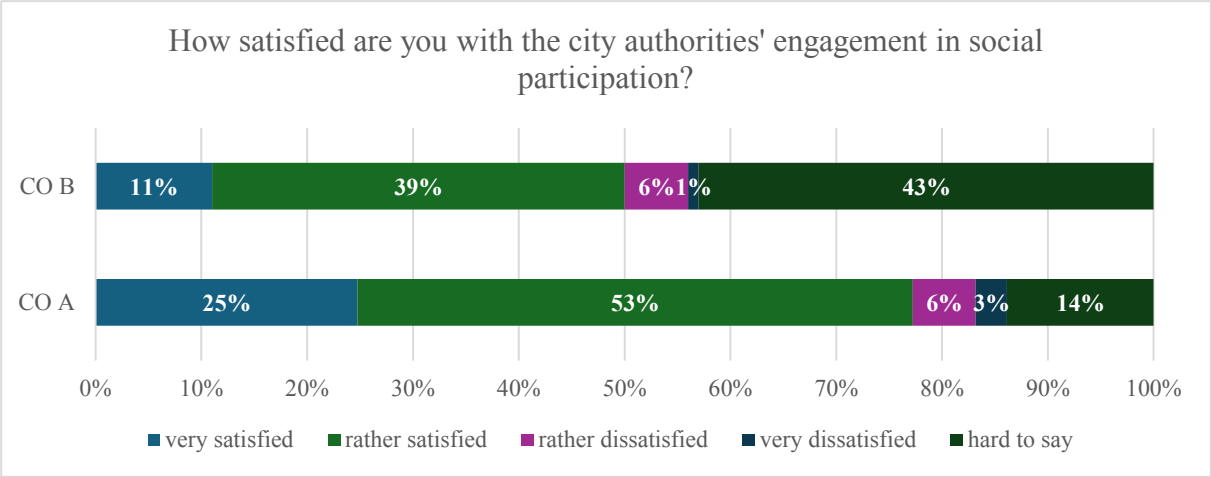

Figure 7. Employee Satisfaction with City Authorities' Engagement in Promoting Social Participation in City Offices A and B.

Source: own elaboration.

Analysis of Figure 7 reveals significant differences in the level of employee satisfaction with the city authorities' engagement in promoting social participation between CO A and CO B. In CO A, the vast majority of respondents express satisfaction: 25% are very satisfied, and 53% are rather satisfied, totaling 78% satisfied employees. In City Office B, the percentage of satisfied employees is much lower: 11% are very satisfied, and 39% are rather satisfied, totaling 50% satisfied. The most significant difference, shown in the chart, concerns the "hard to say" response, which was chosen by 14% of employees in CO A and as many as 43% in CO B. The dominant tendency towards satisfaction in CO A, contrasting with greater uncertainty and a lower level of satisfaction in CO B, suggests that employees in CO A generally rate the involvement of the authorities in social participation more positively than in CO B. The high percentage of "hard to say" responses in City Office B may indicate a lack of clear perception of the authorities' actions in this area or a more complex and ambiguous situation in this city.

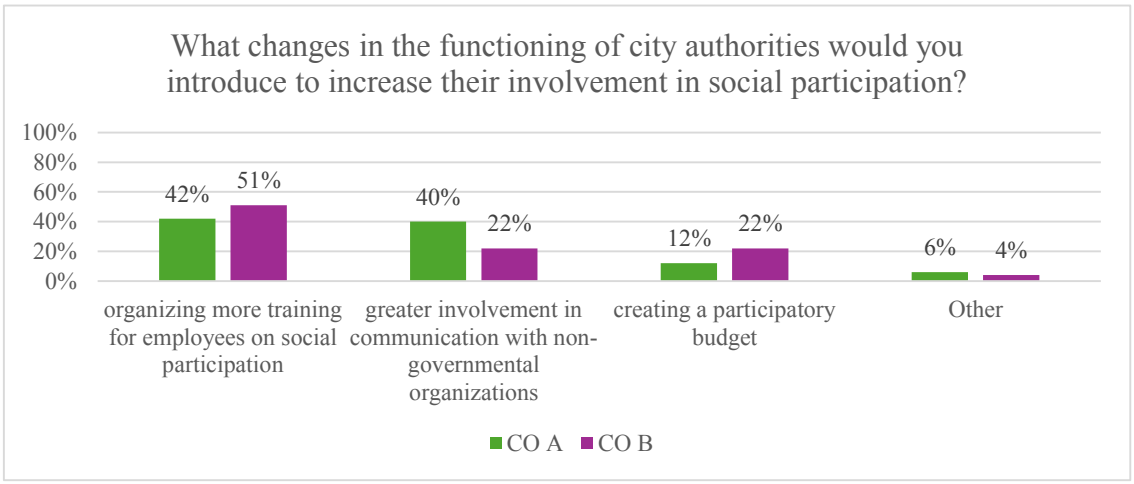

Figure 8. Suggested Changes by City Office A and B Employees to Enhance City Authorities' Engagement in Social Participation (multiple indications).

Source: own elaboration.

Analysis of Figure 8 shows that employees in both cities most often suggest organizing more training for employees on social participation as a key change that could increase the involvement of authorities (CO A 42%, CO B 51%). Figure 8 reveals that this proposal enjoys the greatest support in both locations. The dominant indication of the need for training in both cities, shown in the chart, emphasizes the perceived need to strengthen employee competences in the area of social participation. Differences in further suggestions may reflect specific needs and priorities in improving the functioning of authorities in the context of participation in each of the cities.

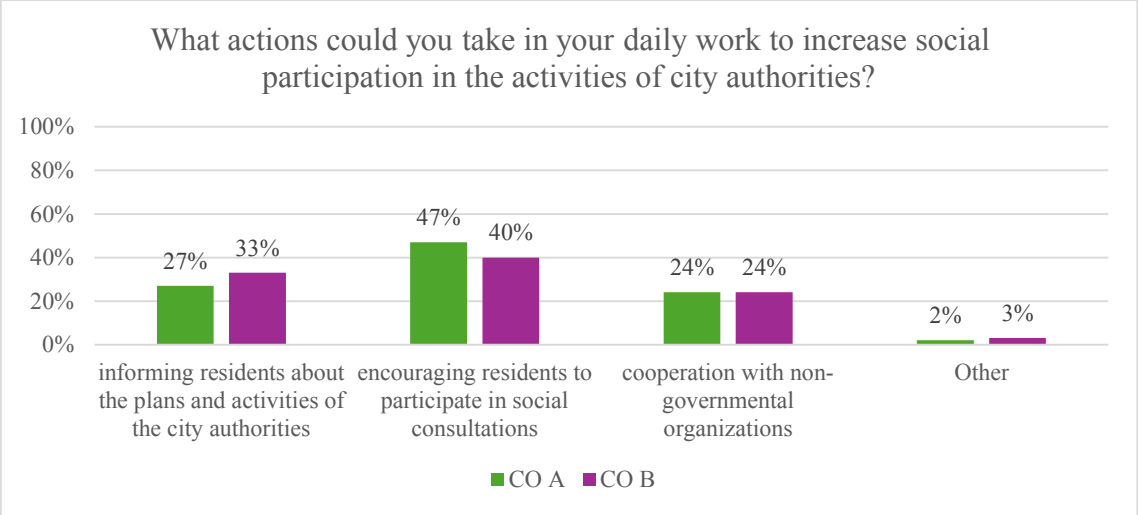

Figure 9. Suggested Actions by Employees to Enhance Their Own Engagement in Social Participation (multiple indications).

Source: own elaboration.

Analysis of Figure 9 shows that employees in both cities most often suggest encouraging residents to participate in social consultations as a key action that they could take in their daily work to increase participation (CO A 47%, CO B 40%). The chart reveals that this proposal enjoys the greatest support in both locations. The dominant emphasis on encouraging participation in consultations, shown in the chart, highlights the perceived role of employees in activating residents. Informing residents about the authorities' activities is also important, indicating the need for transparency. Similar support for cooperation with non-governmental organizations in both cities suggests that employees see potential in partnering with the non-governmental sector in increasing participation.

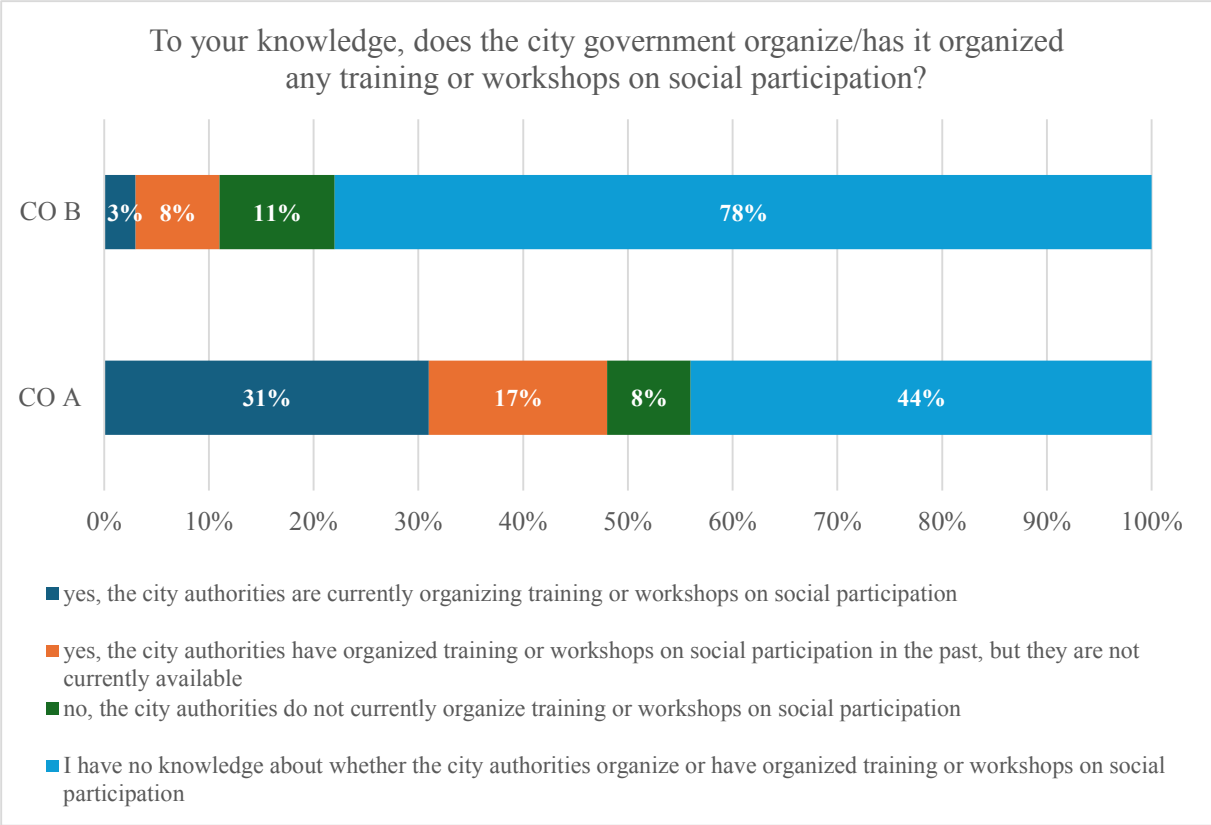

Figure 10. Employee Awareness of City Initiatives Related to Enhancing Social Participation. Source: own elaboration.

Analysis of Figure 10 shows that employees in City Office A are significantly better informed about initiatives related to social participation than employees in City Office B. In City Office B, knowledge on this subject is clearly lower. This difference suggests that it is necessary to improve communication regarding initiatives aimed at increasing employee competence in the area of participation, which is necessary for the effective inclusion of residents in the implementation of the Smart City concept.

4. Discussion

One of the key findings of this study is the significant difference in the assessment of the current level of city authorities' engagement in promoting social participation and in the level of employee satisfaction between the surveyed city offices (Figure 3 and 7). In City Office A, the vast majority of respondents perceive the authorities' engagement as high and express greater satisfaction, while in City Office B, the response 'hard to say' dominates in the assessment of engagement, and the level of satisfaction is much lower. These differences may stem from many factors, including the scale and complexity of the administrative structure of both cities (Manville et al., 2014).

Smart cities are characterized by forward-thinking attitudes and encompass the actions of well-informed and independent citizens (Giffinger et al., 2007). Many researchers (Hollands, 2008; Craglia, Granell, 2014) point to citizens as key players whose participation is essential for the success of urban initiatives (Cornwall, 2008). Thus, the higher assessment of authorities' engagement and greater employee satisfaction in City Office A may reflect more active and visible actions by the authorities to involve citizens in decision-making processes. On the other hand, the lower assessment of engagement and the higher percentage of 'hard to say' responses in City Office B may suggest a lower intensity or visibility of such actions from the employees' perspective, which potentially translates into a lesser sense of influence and satisfaction.

Another key finding of the analysis is the fact that the lack of financial resources was indicated as one of the main barriers to increasing the engagement of authorities in social participation in both surveyed city offices (Figure 4), with this barrier being more strongly emphasized in City Office B. This observation may be related to the financial challenges faced by post-industrial cities in the Silesian region. Economic transformation and the need to restructure local economies often involve limited municipal budgets and the need to allocate funds to more urgent needs related to infrastructure, the environment, or social assistance (James, 2009). In such a context, participatory initiatives, although important for building social capital and sustainable development, may be perceived as less of a priority in the face of more pressing expenditures.

The particularly strong perception of the lack of financial resources in City Office B may reflect a more strained budgetary situation in this city or different priorities in the allocation of available funds compared to City Office A. Research on the economic resilience of post-industrial cities in Poland (Drobniak, Kolka, Skowroński, 2012) indicates that these cities often struggle with the long-term effects of transformation, which may affect their financial capacity in various areas. The processes of industrial restructuring generate long-term consequences for local finances (European Urban and Regional Studies). Thus, access to adequate financial resources is a key factor determining the possibilities of development and implementation of effective strategies for social participation in the surveyed cities.

5. Summary

This article aimed to understand the perception of social participation among public administration employees in City Office A and City Office B, and to identify the determinants of this perception in the context of Smart Cities in Silesia. The conducted survey provided rich empirical material, showing both similarities and differences in employee attitudes in relation to:

- the definition of social participation,
- elements of social participation,
- assessment of authorities' engagement,
- barriers,
- suggested actions,
- level of satisfaction with social participation.

A comparative analysis revealed that while employees in both cities similarly perceive participation as the possibility of influencing decisions, significant differences emerged in the assessment of the current level of authorities' engagement and the level of satisfaction. These differences suggest varying experiences or perceptions of participatory initiatives in both locations. Additionally, the analysis of Figure 10 indicates that employees of City Office A are significantly better informed about initiatives related to social participation than employees of City Office B, which may also affect the differing perceptions. Barriers such as a lack of financial resources were indicated in both cities, though with varying intensity.

Future research could delve deeper into the reasons for the identified differences in perception and satisfaction between the offices, exploring the role of organizational culture and communication strategies. In the context of the low awareness of training in City Office B, it would be purposeful to examine the effectiveness of various information channels in reaching employees with training offers. Furthermore, to obtain a more complete picture of the conditions of social participation in the context of smart cities, it is recommended to broaden the research perspective to include an analysis of the impact of specific instruments supporting participation (including training, as indicated in Figure 10) and to examine the perspective of the residents themselves. Qualitative research, such as in-depth interviews with employees and residents, could provide richer data on experiences and expectations related to participation in the context of local Smart City initiatives.

References

1. Arnstein, S. (1969). A ladder of community participation. *Journal of the American Institute of Planners, 35,* 216-224. doi: 10.1080/01944366908977225
2. Aurigi, A. (2005). *Making the Digital City: The Early Shaping of Urban Internet Space (1st ed.)*. Routledge. doi: https://doi.org/10.4324/9781315249964
3. Babbie, E. (2010). *Badania społeczne w praktyce*. Warszawa: PWN, 538-543.
4. Cardullo, P., Kitchin, R. (2019). Being a 'citizen' in the smart city: up and down the scaffold of smart citizen participation in Dublin, Ireland. *GeoJournal, 84,* 1-13. doi: 10.1007/s10708-018-9845-8

5. Choi, T.H., Wong, Y.L. (2023). Does public consultation affect policy formulation? Negotiation strategies between the administration and citizens. *Journal of Education Policy, 39(3),* 455-479. doi: 10.1080/02680939.2023.2269373
6. Cornwall, A. (2008). Unpacking "participation": Models, meanings and practices. *Community Development Journal, 43*, 269-283. doi: 10.1093/cdj/bsn010
7. Drobniak, A., Kolka, M., Skowroński, M. (2012). Transition and urban economic resilience in Poland's post-industrial cities: The case of Katowice. *Regions Magazine, 286*, 13-15. doi: 10.1080/13673882.2012.10515116
8. Eremia, M., Toma, L., Sanduleac, M. (2017). The smart city concept in the 21st century. *Procedia Engineering, 181*, 12-19. doi: 10.1016/j.proeng.2017.02.357
9. Fung, A., Wright, E.O. (2001). Deepening democracy: Institutional innovations in empowered participatory governance. *Science and Society, 70,* 566-569. doi: 10.1177/0032329201029001002
10. Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler, N., Meijers, E. (2007). *Smart cities: Ranking of European medium-sized cities.* Vienna: Vienna University of Technology.
11. Guerrero-Pérez, A.D., Huerta, A., González, F., López, D. (2013). *Network architecture based on virtualized networks for smart cities.* Retrieved from: https://smartcities.ieee.org/images/files/pdf/ngn_sdn_v3.1.0.pdf, 10.04.2025.
12. Łobocki, M. (2007). *Wprowadzenie do metodologii badań pedagogicznych*. Kraków: Wydawnictwo Impuls.
13. Manville, C., Cochrane, G., Cave, J., Millard, J., Pederson, J., Thaarup, R., Liebe, A., Wissner, M., Massink, R., Kotternik, B. (2014). *Mapping Smart Cities in the EU (Policy Department A: Economic and Scientific Policy).* European Union. Retrieved from: http://www.europarl.europa.eu/RegData/etudes/etudes/join/2014/507480/IPOL-ITRE_ET(2014)507480_EN.pdf
14. Putri, D., Trisnaningsih, S. (2024). Analysis of the effect of budget participation on budgetary slack: Study literature review. *Formosa Journal of Multidisciplinary Research, 3,* 263-272. doi: 10.55927/fjmr.v3i3.8585
15. Rowe, G., Frewer, L.J. (2005). A typology of public engagement mechanisms. *Science, Technology and Human Values, 30,* 253-255. doi:10.1177/0162243904271724
16. Simmie, J. (2009). The economic resilience of regions: Towards an evolutionary approach. *Cambridge Journal of Regions, Economy and Society, 3*, 27-43. doi: 10.1093/cjres/rsp029

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MARKETING COMMUNICATION AS A TOOL SUPPORTING ARTIFICIAL INTELLIGENCE ACCEPTANCE IN MEDICAL SERVICES

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Purpose: The research aimed to identify marketing communication determinants affecting AI's positive image in medicine and to identify factors that may enhance or undermine this technology's acceptance.
Design/methodology/approach: The research was based on a self-developed survey questionnaire that examined respondents' beliefs about artificial intelligence in healthcare and the relevance of selected elements of marketing communications. The survey was conducted on 1,000 adults living in Poland.
Findings: Nearly 70% of respondents believe AI can improve the health services' quality, but prefer to remain with health services provided traditionally. 69% of the respondents indicate a deficiency of information related to AI in medicine, with the following considered the best sources of information in this regard: scientific publications, medical institution websites, doctors' recommendations, and medical services. The biggest concerns regarding AI's use in medicine are the lack of legal liability, the risk of misdiagnosis, and the inability to ask further questions. The research results indicate that communication regarding AI use in medicine should be conducted in an educational rather than an advertising campaign format. It is also good practice to support the message with certificates from health institutions and case studies on patient stories.
Research limitations/implications: Respondents' answers in the survey were declarative and concerned selected aspects of marketing communications. In the next research stage, it is worthwhile to make an in-depth analysis of the various marketing messages for AI promotion in healthcare.
Practical implications: The research results obtained can be used by campaign creators to promote artificial intelligence use in healthcare. Identified factors can contribute to medical messages' value in raising acceptance of proposed solutions.
Originality/value: The research verified the influence of demographic characteristics on artificial intelligence perceptions in healthcare and the impact of these characteristics on selected message elements. The research identified marketing communication factors influencing the increased acceptance of artificial intelligence in healthcare.
Keywords: Artificial intelligence in healthcare, AI acceptance.
Category of the paper: Research paper.

1. Introduction

In recent years, artificial intelligence has changed the functioning of almost all industries, including the medical industry. Therefore, healthcare is transforming the traditional medical relationship from human-doctor interaction to healthcare enriched with another variable, new technology. Artificial intelligence (AI) development in the field of health services constantly offers new perspectives, but it also continues to raise huge concerns. Despite the high usage potential, patients remain skeptical about AI and prefer doctors over such technology (Wang, Siou, 2018). Therefore, the acceptance of new technologies in medicine (Ochnik et al., 2024) and trust in AI by both patients and healthcare professionals is a crucial aspect of implementing such solutions. Trust is essential for acceptance, and users must have confidence in the accuracy and complementary role of artificial intelligence over clinical judgment (Nash et al., 2023).

Building trust in AI in medicine begins with the acceptance of such solutions by doctors, whose authority can increase the systems' credibility (Asan et al., 2020). From the patient's perspective, there is a need to better understand and explain how AI works, making information fusion a crucial activity (Albahri et al., 2023). Numerous studies explain the trust phenomenon in AI in healthcare by identifying factors affecting it. Key factors identified that influence healthcare professionals' confidence in medical AI and enhance clinician-machine collaboration include: explainability, transparency, interpretability, usability, and education (Tucci et al., 2021). For patients, accountability, risk perception, facilitating conditions and social impact are important (Wang et al., 2023). Researchers also indicate the user and system characteristics that play an important role in trusting artificial intelligence in healthcare. Both groups of users, including doctors and patients, are influenced by human factors such as knowledge, expectations, mental models, self-efficacy, user type, age, and gender (Jermetus et al., 2022), as well as technology knowledge and education level (Zhang et al., 2020). Additionally, it was indicated that psychosocial factors, including perceived ease of use and usability, are important to both healthcare professionals and patients (Khanijahani et al., 2022). AI acceptance in healthcare is also influenced by systemic factors such as data privacy and security (Jermetus et al., 2022), organizational infrastructure, and stakeholder perspectives (Sides et al., 2023). According to Zang and Zang, ethical issues, including data quality, algorithmic bias and responsibility attribution, also play an important role in this process (Zhang, Zhang, 2023). Based on the literature, confidence in artificial intelligence is generally lower than in doctors, especially for high-risk diagnoses (Juravle et al., 2020). Interestingly, confidence in AI does not increase when people are informed that AI is superior to the human doctor (Juravle et al., 2020). These results emphasize the need for targeted promotional efforts to increase confidence in artificial intelligence in healthcare.

The literature indicates that marketing communication channels significantly influence the perceived usefulness and ease of use of technological innovations. The technology acceptance model assumes that perceived usefulness and ease of use are key determinants of solutions adopted by users (Wang et al., 2008). Therefore, effective marketing communications can also influence AI acceptance in medicine while requiring a proactive attitude and open communication between developers, users, and the general public (Wind et al., 2019). Sebastian's research indicates that effective communication strategies include the use of rhetorical approaches - ethos, pathos, and logos in promotional materials (Sebastian et al., 2023). The authors indicate that promoting AI products to patients through rhetoric-based advertising can help overcome factors hindering AI adoption by mitigating users' concerns about using a new AI agent in the care process (Sebastian et al., 2023). Using the message on the following strategies can increase AI acceptance in medicine (Sebastian et al., 2023):

- Ethos - strategy using credibility and ethics to persuade, mitigate the perceived risks of using AI. In addition, supporting the message with a known, trusted person increases consumer confidence in the product, thereby increasing adoption (Hutchesson et al., 2013);
- Pathos - a strategy that uses emotion and persuasion, mitigate concerns about using AI. It is based on the premise that if someone similar to us recommends a product with a happy emotion, it improves the consumer's innate innovativeness (Skin et al., 2016);
- Logos - a strategy that uses logical reasoning and evidence based on facts and historical data to mitigate perceived risks. Basing the message on facts and historical data.

When creating a communication strategy, it is also necessary to adapt the message to the target audience because, due to knowledge asymmetry, the needs of medical personnel and patients will be different. From the medical personnel's perspective, messages based on AI knowledge and gaining practical experience among healthcare professionals are crucial (Chen et al., 2022). Conversely, patients continue to have concerns about data privacy, ethical use and security (Aggarwal et al., 2020). Marketing communications should emphasize building trust through assurances about data security, educating patients on how to protect their privacy, and being transparent about system use of medical data. Regardless of the target audience, the primary marketing communications role for AI use in medicine remains education to mitigate concerns about new technology change and adoption. Education allows for a better understanding of AI's capabilities and limitations, and increased access to knowledge and information can be achieved through educational meetings with committed local leaders and educational promotional materials (Chen et al., 2022).

2. Methodology

The research aimed to identify the determinants of marketing communications affecting the positive image of AI in medicine and to identify factors that may enhance or undermine this technology's acceptance. Acceptance is defined as the intention or willingness to use, purchase, or try a good or service (Kelly et al., 2023).

In developing the stated goal, the following research questions were formulated:

1. Do and how do demographic characteristics differentiate the preferred marketing communications elements for AI use in medicine?
2. What concerns do patients have about AI use in healthcare?
3. What measures can enhance patients' comfort with AI in medical services?
4. What marketing communication channels are preferred for getting the information about AI in health care?

The research verified the influence of demographic characteristics on the answers to the questions posed in the questionnaire. The $\mathcal{X}^2$ independence test was used to analyze the relationship between qualitative characteristics. Let $(\Omega, \mathcal{F}, P)$ be a probability space and random variables $X: \Omega \to S_X = \{a_1, \dots, a_k\}$, $Y: \Omega \to S_Y = \{b_1, \dots, b_m\}$. At the significance level $\alpha, 0 < \alpha < 1$ a working hypothesis:

H_0: no relationship between features X and Y (features are independent), i.e. for any

$$a \in S_x, b \in S_Y$$
$$P(X = a, Y = b) = P(X = a)P(Y = b) \tag{2.1}$$

and the alternative hypothesis

H_1: there is a relationship between the features X and Y, i.e. for any $a \in S_x, b \in S_Y$

$$P(X = a, Y = b) \neq P(X = a)P(Y = b) \tag{2.2}$$

were formulated.

Let $\{(x_i, y_i)\}_{1 \le i \le n}$ denote the sequence of realizations of features X and Y. The numbers $n_{ij} = \#\{s: 1 \le s \le n, x_s = a_i, y_s = bj\}$ are determined where # (cardinality) means the power of the set, $1 \le i \le k, 1 \le j \le m$. In addition, the marginal numbers $n_{i\cdot} = \sum_{j=1}^{m} n_{ij}$ and $n_{\cdot j} = \sum_{i=1}^{k} n_{ij}$ were determine where $\sum_{j=1}^{m} n_{\cdot j} = \sum_{i=1}^{k} n_{i\cdot} = n$. Test statistic (Hastie, 2009).

$$\chi^2 = \sum_{i=1}^{k} \sum_{j=1}^{m} \frac{(n_{ij} - \hat{n}_{ij})^2}{\hat{n}_{ij}}, \tag{2.3}$$

where $\hat{n}_{ij} = \frac{n_{i\cdot} n_{\cdot j}}{n}$, has an $\mathcal{X}^2$ distribution with $(k-1)(m-1)$ degrees of freedom. Therefore, the test probability $p_{val} = P(\mathcal{X}^2 \ge \chi^2)$. If $p_{val} \le \alpha$, then at the significance level α the working hypothesis is rejected in favor of the alternative hypothesis, so there is a relationship between the characteristics X and Y.

The magnitude of the χ^2 statistic does not show the strength of the relationship between the X and Y variables. To estimate the strength of the relationship (correlation) between these variables, we determine the V-Cramer coefficient.

$$V_{Cramer} = \sqrt{\frac{\chi^2}{n(\min(k,m)-1)}} \tag{2.4}$$

The conventional interpretation of the relationship strength between features is as follows:

- $V_{Cramer} \in [0,0.3)$ - weak relationship between features X and Y;
- $V_{Cramer} \in [0.3,0.5)$ - moderate relationship between features X and Y;
- $V_{Cramer} \in [0.5,1]$ - strong relationship between features X and Y.

The research was conducted using a self-developed survey questionnaire with questions grouped into 7 thematic areas and a metric. A Likert scale was used in questions examining respondents' beliefs about the relevance of each component of communication messages. To assess the survey questionnaire's reliability, an internal consistency analysis was conducted using Cronbach's alpha coefficient (Table 1). Cronbach's alpha coefficient values were above 0.78, indicating the research tool's high reliability.

Table 1.
Assessment of the survey questionnaire's reliability

Indicators	set_2	set_3	set_4	set_5	set_6	set_7
Cronbach's alpha	0.8145365	0.7836866	0.8335960	0.9201844	0.9184653	0.8713789
Guttman' lambda	0.8073954	0.8166592	0.8281923	0.9328445	0.9380662	0.8721875
McDonald's omega	0.8573208	0.8735700	0.8641502	0.9389612	0.9419952	0.9016609

Source: own elaboration based on survey results.

The study encompassed a sample of 1000 adult Poles, participants of the online research panel *Badanie Opinii*. This criterion was necessary due to the selected sampling frame. The sample included a representative distribution by age and gender based on data from Statistics Poland (GUS), derived from the 2021 National Census, updated as of December 7, 2023.

To determine the weighting factors enabling representative estimates for the population of online panel users, the proportion of individuals using the Internet (defined as using the Internet at least once a week) by age and gender was taken into account. These weights were then used to adjust the population figures, multiplying the number of individuals in each age and gender group by the corresponding weighting factor:

- Ages 18-24: 0,98 for women, 1,00 for men,
- Ages 25-34: 1,00 for women, 0,99 for men,
- Ages 35-44: 0,96 for women, 0,96 for men,
- Ages 45-54: 0,88 for women, 0,85 for men,
- Ages 55-64: 0,69 for women, 0,64 for men
- Aged 65 and over: 0,36 for women, 0,52 for men.

3. Results

The sample size was 1000 participants and was representative of Poland. All participants signed a written consent and were eligible for the study (over 18 years old). No responses were omitted. The surveyed group included people from all the distinguished age ranges. Only 3 respondents indicated a different gender, the rest declared that they were female or male. Women slightly outnumbered men (50,3%). The largest age group was respondents aged 35-44 (24.8%), living in large cities (over 200,000 inhabitants). Respondents were also asked whether they were professionally involved in the medical or related profession and whether they were professionally involved in AI. Only 12.3% of the sample is in the medical profession, and 10.40% is professionally related to the AI sector. The research sample's characteristics are presented in Table 2.

Table 2.
Research sample characteristics

Variable		**n**	**%**
Gender	Women	503	50.30%
	Men	494	49.40%
	Other	3	0.30%
Age	Up to 24 years	103	10.30%
	More than 25 to 34 years	194	19.40%
	More than 35 to 44 years	248	24.80%
	More than 45 to 54 years old	195	19.50%
	More than 55 to 64 years	126	12.60%
	Over 65 years	134	13.40%
Place of residence	Rural	205	20.50%
	City up to 10 thousand residents	43	4.30%
	City of more than 10 to 50 thousand residents	191	19.10%
	City of more than 50 to 100 thousand residents	126	12.60%
	City of more than 100 to 200 thousand residents	117	11.70%
	City of more than 200 thousand residents	318	31.80%
Medical or related profession	Yes	117	11.70%
	No	883	88.30%
Profession related to the AI sector	Yes	104	10.40%
	No	896	89.60%

Source: own elaboration based on survey results.

In the first part of the survey, respondents were asked about their attitudes toward AI use in healthcare. Respondents rated the truthfulness of the following statements on a four-point Likert scale:

1. Artificial intelligence can improve health service quality.
2. Artificial intelligence may replace doctors in the future.
3. I prefer traditional medical consultations without artificial intelligence involvement.
4. I would be willing to use AI diagnosis instead of visiting a doctor if it was faster and more affordable.
5. I prefer when the final medical decision belongs to the doctor, not to AI.

The respondents' evaluation results are presented in Table 3. The majority of respondents (69.5%) believe that AI can improve health services quality (answers “rather yes” and “yes”). Despite this belief, those surveyed prefer to stay with services provided traditionally, which means medical consultations without AI (84.7% of responses) and final decision-making by the doctor (89.5% of affirmative responses - “rather yes” and yes"). Moreover, even in a situation where AI would provide faster and more affordable access to a medical service, 28% of respondents would certainly use it, while 37.10% would rather not use such an option. The majority of respondents (76.2%) do not see a threat for AI to replace doctors in the future (answers “no” and “rather no”). Performing statistical analysis of the relationship between responses to these questions and demographic variables, statistically significant relationships were observed for statements 1, 2, 4, and the variable gender, 3 and the variable age, and 2 and 4 and the variable profession related to AI (Table 4). Considering the gender variable, it was noticed that:

1. Men are far more likely to agree with the statement that AI can improve health services quality (50.40% “rather yes” and 23.48% “yes” responses) than women (48.71% “rather yes” and 16.5% “yes” responses).
2. Men are more likely to agree with the statement that AI could replace doctors in the future (18.22% “rather yes” and 10.93% “yes” responses) than women (13.92% “rather yes” and 4.77% “yes” responses).
3. Men would be more likely to use AI diagnosis if it were faster and more affordable (28.14% “rather yes” and 11.74% “yes” responses) than women (21.87% “rather yes” and 8.15% “yes” responses).

Considering respondents' age and preference for traditional medical consultations, it can be seen that the need for traditional consultations increases with age (“yes” answers in the group from 18-24 years 40.78%, from 55-64 years 53.17% and over 64 years 61.94%). Meanwhile, analyzing the dependencies regarding the AI occupation variable, it can be noted that:

1. AI professionals are significantly more likely to agree with the statement that AI could replace doctors in the future (28.85% “rather yes” and 15.38% “yes” responses) than others (14.51% “rather yes” and 6.92% “yes” responses);
2. AI professionals are more likely to use an AI diagnosis if it were more affordable and quicker compared to a traditional visit (36.54% “rather yes” and 19.23% “yes” responses) than others (23.66% “rather yes” and 8.82% “yes” responses).

Table 3.
Respondents' attitudes towards AI in healthcare

	No	Rather no	Rather yes	Yes	Total
Artificial intelligence can improve health service quality.	11.70%	18.80%	49.60%	19.90%	100.00%
Artificial intelligence may replace doctors in the future	40.30%	35.90%	16.00%	7.80%	100.00%
I prefer traditional medical consultations without artificial intelligence involvement	4.80%	12.30%	35.70%	47.20%	100.00%

Cont. table 3.

I would be willing to use AI diagnosis instead of visiting a doctor if it was faster and more affordable	28.00%	37.10%	25.00%	9.90%	100.00%
I prefer when the final medical decision belongs to the doctor, not to AI	4.50%	6.00%	28.40%	61.10%	100.00%

Source: own elaboration based on survey results.

Table 4.

Influence of gender, age, and AI-related profession characteristics on attitudes toward AI use in medicine

Dependencies	**Statistics**	**p_val**	**Hyp.**	**Cramer_V**
Gender				
1 - Artificial intelligence can improve health service quality.	13.964729	0.03003	H1	0.08356
2 - Artificial intelligence may replace doctors in the future.	29.058557	5.9304×10^{-5}	H1	0.12050
4 - I would be willing to use AI diagnosis instead of visiting a doctor if it was faster and more affordable.	21.037860	0.00181	H1	0.10260
Age				
3 - I prefer traditional medical consultations without artificial intelligence involvement.	35.558723	0.00205	H1	0.10890
AI-related profession/other				
2 - Artificial intelligence may replace doctors in the future.	26.9160576	6.1308×10^{-6}	H1	0.16410
5 - I prefer when the final medical decision belongs to the doctor, not to AI.	26.4048748	7.8458×10^{-6}	H1	0.16250

Source: own elaboration based on survey results.

Respondents were asked to rate the truthfulness of the statement "I feel I lack sufficient information on using AI in medicine" on a four-point Likert scale. 29.10% answered "yes", 40.10% "rather yes", 20% "rather no", and 10.80% "no". The results indicate that more than 69% of respondents feel, to varying degrees, a shortage of information regarding AI use in medicine. Respondents were also asked about communication channels and tools relevant to learning about AI in medicine. To achieve this, they evaluated the significance of the identified potential channels on a five-point scale, where 1 meant not very important, while 5 meant very important. The mean value and standard deviation were then calculated for the responses obtained (Table 5). The sources of information on AI in healthcare for respondents are not: advertisements (2.422), blogs (2.567), podcasts (2.72), radio (2.816), daily press (2.847), forums and discussion groups (2.878) and television (2.931). Meanwhile, respondents rated the following highest: scientific publications (3.83), medical facility websites (3,823), doctor recommendations (3,789), and medical websites (3,696). Analyzing the statistical relationship between the communication channels most highly rated by respondents and demographic variables, statistically significant relationships were observed for the medical facilities website vs. gender and age variable, physician recommendations vs. age variable, medical or allied health profession and AI-related profession, and scientific publications vs. age variable (Table 6). The following relationships were observed:

1. Medical facility websites - received higher ratings from women (average response of 3.93) compared to men (average response of 3.71), and older individuals (those over 64 years old) rated them even higher, with an average response of 4.32.
2. Doctors' recommendations - received the highest ratings from older respondents, with an average score of 4.172 from those over 64. Additionally, individuals not in the medical or allied health professions rated these recommendations (a mean score of 3.65, others 3.8). Furthermore, respondents who are not professionally engaged with AI gave an average rating of 3.8, and others gave 3.67;
3. Scientific publications - were rated highest by older respondents (average response for those over 64 years old 4.03).

Table 5.
Evaluation of communication channels/tools in acquiring knowledge about AI in medicine

Communication channels/tools	Average response value	Standard deviation
Government and health institution websites	3.693	1.216
Medical facility websites	3.823	1.188
Medical websites	3.696	1.158
Social media	2.812	1.303
Advertisements	2.422	1.278
Doctors' recommendations	3.789	1.179
Relatives' recommendations	3.485	1.159
Scientific publications	3.83	1.124
Daily press	2.847	1.198
Industry press	3.243	1.166
Radio	2.816	1.223
Television	2.931	1.256
Podcasts	2.72	1.283
Blogs	2.567	1.222
Forums and discussion groups	2.878	1.221
Medical conferences and events	3.6	1.162

Source: own elaboration based on survey results.

Table 6.
Influence of gender, age, AI-related profession and medical or related profession characteristics on evaluation of selected communication channels in acquiring knowledge about AI in medicine

Dependencies	Statistics	p_val	Hyp.	Cramer_V
Gender				
Medical facility websites	20.160702	0.00974	H1	0.10040
Age				
Medical facility websites	67.043930	5.4919×10^{-7}	H1	0.12950
Doctors' recommendations	49.355490	0.00027	H1	0.11110
Scientific publications	35.798743	0.01624	H1	0.09460
AI-related profession				
Doctors' recommendations	13.6433884	0.00852	H1	0.11680
Medical and related profession				
Doctors' recommendations	10.2246303	0.03681	H1	0.10110

Source: own elaboration based on survey results.

Another issue was potential concerns about AI use in healthcare. Respondents rated the importance of the identified potential risks on a five-point scale, where 1 meant not very important and 5 meant very important. The mean value and standard deviation were then calculated for the responses obtained (Table 7). For respondents, all of the points identified were important (mean response above 3.6), with the biggest concerns being lack of legal liability (4.13), risk of misdiagnosis (4.027), and inability to ask further questions (4.023). Analyzing the statistical relationship between AI concerns and demographic variables, statistically significant relationships were observed for the variables gender and age and risk of misdiagnosis, lack of legal liability and inability to ask further questions (Table 8).

The following relationships were observed:

1. Risk of misdiagnosis - concerns about the occurrence of this threat were, on average, rated higher by women (mean response of women 4.13, men 3.91) and those aged 55-64 (mean response of 4.18) and those aged over 64 (mean response of 4.09), while the lowest mean response was obtained by those aged 18-24 (mean response of 3.84).
2. Lack of legal liability - women had a higher average response value to this question (4.26 women, 3.99 men), and older respondents- over 64 years of age (average response value of 4.29, while for the group of the youngest respondents, 18- 24 years of age, the value was 3.75).
3. Inability to ask further questions - women had a higher average response value to this question (4.20 women, 3.85 men), and older respondents - over 64 years old (average response value of 4.36, while for the group of the youngest respondents 18-24 years old the value was 3.75).

Table 7.
Concerns about artificial intelligence in medicine

Threats	Average response value	Standard deviation
Lack of empathy and contact with the other person	3.745	1.273
Lack of intuition and human experience	3.992	1.059
Risk of misdiagnosis	4.027	1.014
Data security	3.787	1.176
Lack of legal liability	4.13	1.030
Fear of dependence on technology	3.649	1.197
Lack of consideration of non-standard/unique factors	3.897	1.059
Inability to ask further questions	4.023	1.032
Ambiguity of decisions	3.982	0.982

Source: own elaboration based on survey results.

Table 8.
Influence of gender and age characteristics on highest rated AI concerns

Dependencies	Statistics	p_val	Hyp.	Cramer_V
Gender				
Risk of misdiagnosis	22.132226	0.00468	H1	0.10520
Lack of legal liability	20.656098	0.00812	H1	0.10160
Inability to ask further questions	35.837439	1.8805×10^{-5}	H1	0.13390

Cont. table 8.

Age				
Risk of misdiagnosis	36.697322	0.01272	H1	0.09578
Lack of legal liability	34.718136	0.02166	H1	0.09316
Inability to ask further questions	39.766119	0.00535	H1	0.09971

Source: own elaboration based on survey results.

Considering the existing concerns, respondents were asked about actions they believe could enhance the comfort of using AI in healthcare. The respondents rated the importance of the identified potential actions on a five-point scale, where 1 indicated not very important and 5 indicated very important. The mean value and standard deviation were subsequently calculated for the obtained responses (Table 9). Assigning human traits to AI, like avatars or tones of voice, lacked meaningful purpose. Meanwhile, the most important measures according to respondents that could increase the comfort level with AI concern the following areas:

1. Opportunities to check AI diagnosis i.e.: additional consultation with a doctor - after AI diagnosis (4,177) and the possibility to compare AI diagnosis with a doctor's diagnosis (4,108).
2. Legal issues regulation i.e.: legal regulations related to personal data security (4.093) and legal regulations related to AI liability (4.092).

Statistical analysis of the highest rated responses and demographic variables revealed the following relationships (Table 10):

1. Ability to compare AI's diagnosis with the doctor's diagnosis - the average response of women 4.19, men 4.01. Furthermore, it was noted that with age the relevance of this activity increases for respondents. The average response for those over 64 years old was 4.5, while for those from 18-24 years old it was 3.88.
2. Ability to consult a doctor after AI analysis - the importance of this activity increases for respondents with age. The average response for those over 64 years old was 4.61, while for those from 18-24 years old it was 3.85.
3. Legal regulations related to liability - the importance of this activity increases for respondents with age. The average response for those over 64 was 4.36, while for those from 18-24 it was 3.74. Surprisingly, slightly higher importance was given to this activity for non-medical professionals (average response of 4.11, while for medical professionals the average response was 3.93).
4. Legal regulations related to data security - this activity was most important for the elderly - the average response for those over 64 was 4.39, while for those from 18-24 it was 3.82.

Table 9.
Activities that can increase the comfort level with AI in healthcare

Activities	Average response value	Standard deviation
Doctors and medical facilities recommendation	3.425	1.176
Positive feedback from other patients	3.535	1.194
Scientific studies confirming AI's effectiveness	3.624	1.199
Clear explanation of the basis for AI's diagnosis	3.818	1.154
Ability to compare AI's diagnosis with the doctor's diagnosis	4.108	1.063
Access to the history of previous AI analyses and decisions	3.757	1.125
Ability to verify the sources from which AI draws its knowledge	3.866	1.149
AI certification by medical institutions	3.852	1.217
A well-known brand name for the AI solution	3.164	1.295
Ability to consult a doctor after AI analysis	4.177	1.034
Intuitive mobile app or website	3.439	1.179
Ability to use AI at any time (24/7)	3.698	1.211
Giving AI "human" characteristics, e.g. avatar, voice	2.995	1.293
Legal regulations related to AI liability	4.092	1.101
Legal regulations related to data security	4.093	1.112

Source: own elaboration based on survey results.

Table 10.
Influence of gender, age, and medical or related profession characteristics on highest-rated activities that can increase comfort in using AI in healthcare

Dependencies	Statistics	p_val	Hyp.	Cramer_V
Gender Ability to compare AI's diagnosis with the doctor's diagnosis	17.617465	0.02428	H1	0.09385
Age Ability to compare AI's diagnosis with the doctor's diagnosis	48.594254	0.00035	H1	0.11020
Ability to consult a doctor after AI analysis	84.274050	7.3010×10^{-10}	H1	0.14510
Legal regulations related to AI liability	39.643500	0.00554	H1	0.09955
Legal regulations related to data security	43.471531	0.00177	H1	0.10420
Medical and related profession Legal regulations related to AI liability	16.9952416	0.00194	H1	0.13040

Source: own elaboration based on survey results.

The final group of issues concerned perceptions of selected marketing communications elements used to promote AI in medicine. In this case, a four-point Likert scale was also used to help assess perceptions of selected activities (Table 11). Respondents are convinced that communication about AI use in medicine should be conducted in an educational rather than advertising campaign format (39.5% "yes" and 40.5% "rather yes" responses). According to respondents, it is also good practice to support the message with certificates from health institutions (67.5% of respondents state that this can influence their AI decisions). Respondents also agree with statements that promotional materials should be prepared professionally (46.7% of responses "rather yes," and 18.10% "yes"), and that a good element of communication is a case study containing stories of patients using AI (40.9% of responses "rather yes," and 22.50% "yes"). Statistical evaluation revealed significant correlations between the need to promote AI educationally and the age variable (statist. 40.111626, p_val 0.00044,

Cramer V 0.11560). The oldest respondents - people over 64 years - see a greater need for educational campaigns; in this group, as many as 50.75% answered “yes” to this question and 41.04% “rather yes”.

Table 11.
Evaluating perceptions of selected marketing communication activities regarding AI use in healthcare

	No	Rather no	Rather yes	Yes	Total
Professionally prepared marketing materials (e.g., website, brochures) about AI solutions in medical services make me perceive these solutions as more professional and convincing	12.40%	22.80%	46.70%	18.10%	100.00%
AI in medicine should be promoted educationally, not just in an advertising way	7.10%	12.90%	40.50%	39.50%	100.00%
Certification and official AI approval by health institutions may influence my decision to try it	9.00%	18.50%	44.20%	28.30%	100.00%
I will be more willing to use AI if marketing communications include stories from patients who have benefited from it	11.80%	24.80%	40.90%	22.50%	100.00%

Source: own elaboration based on survey results.

4. Conclusion

New technologies like AI cause anxiety and fear of the unknown (Chen, 2025), therefore, they require an information campaign before they are accepted by users. The survey revealed that respondents are aware of AI development in the medical field. 69.5% of respondents indicate that AI can improve health services quality, results that are consistent with Gao's findings (Gao et al., 2020). Despite this awareness, they still do not fully accept the use of artificial intelligence in healthcare, as evidenced by the fact that respondents prefer to stay with services provided traditionally, which means medical consultations without AI and final decision-making by the doctor. This suggests that AI is best positioned as a complementary tool rather than a replacement for human decision-making (Almeida et al., 2025). Respondents' biggest concerns about AI in healthcare included: lack of legal accountability, risk of misdiagnosis, and inability to ask further questions whenever anything was unclear, with women and older respondents feeling these concerns to a greater extent. This result is consistent with previous scientific findings in this area. A study conducted by D. Khullar found that the majority of respondents were concerned about the unintended consequences of AI, including misdiagnosis (91.5%), privacy violations (70.8%), and less time spent with doctors (69.6%) (Khullar et al., 2022). Research results indicate that more than 69% of respondents feel, to varying degrees, information deficiency related to AI use in medicine, which may affect the acceptance level of these solutions (Robertson, 2023). The research also found that those

working in the AI sector are more accepting of AI's use in healthcare- they are more likely than other groups to say that AI could replace doctors in the future and are more likely to use AI diagnosis if it were more affordable and quicker compared to a traditional visit. This result may be due to greater knowledge of AI among this respondent group, which in turn may have an impact on the higher level of technology acceptance. One way to build acceptance of new technologies is through properly conducted marketing communications (Wind et al., 2019). The most preferred communication channels for AI in healthcare by respondents are: scientific publications, medical facility websites, doctor recommendations and medical websites. It is worth emphasizing that the indicated sources are rated higher by older people (over 64 years old), while recommendations by doctors were rated higher by those not in the medical or related professions and those not professionally involved in the AI sector. Respondents also identified activities that could increase the user experience with AI, thus influencing the technology's acceptance. The main areas concern: the ability to verify the AI diagnosis, i.e.: additional consultation with a doctor - after the AI diagnosis and the ability to compare the AI diagnosis with the doctor's diagnosis, and the legal regulation of legal issues, i.e.: legal regulations related to personal data security and legal regulations related to AI liability. Therefore, it seems reasonable to emphasize these aspects in AI communications. Research indicates that communication about AI use in medicine should be conducted in an educational rather than an advertising campaign format. It is also good practice to indicate in the message that AI technology is supported by certificates from health institutions and professionally prepared marketing materials like brochures. Complementing the message that contributes to AI's acceptance in healthcare, according to respondents, are materials containing stories of patients who have benefited from the use of artificial intelligence to treat diseases.

The results of the conducted research allow for the formulation of recommendations for the healthcare sector, including medical service providers, technology developers, and regulatory bodies. Given the numerous concerns surrounding the use of artificial intelligence (AI) in healthcare, it is essential to design communication campaigns grounded in education. For medical service providers, such as hospitals and physicians, marketing efforts should clarify that AI serves as a support tool rather than a replacement for the physician, explicitly emphasizing that the final decision always rests with a human. A good practice in this regard would be to involve healthcare professionals directly in marketing communication, where they could act as credible ambassadors. From the perspective of technology developers, communication strategies should be based on storytelling and include case studies that present real patient experiences. It is also recommended to employ human-centered metaphors—such as referring to AI as a “patient assistant” rather than an “algorithm” or “AI system”. To ensure comprehensive communication, regulatory authorities should also be actively involved, for example, by initiating nationwide educational campaigns about AI in healthcare, akin to those conducted for vaccinations. The coherence of messaging is crucial; thus, educational initiatives led by the government, healthcare providers, and technology

developers should not be contradictory but rather complementary, employing consistent terminology.

The content of communication should explain what AI is and highlight the benefits of its application in healthcare. It is recommended to develop diversified communication strategies that take into account patients' level of knowledge, age, gender, as well as their specific needs and concerns. Message framing may be based on emotional appeals that draw on empathy, safety, and hope. In such cases, messages can refer to care for the patient and the safety of their family. Furthermore, content creators should avoid using technological jargon, which may render the message incomprehensible to patients.

When constructing marketing messages related to AI in healthcare, it is essential to consider ethical aspects, particularly in relation to sensitive issues such as personal data protection and diagnostic errors. Transparency and communicative honesty must serve as the foundation of such efforts. Consequently, marketing communication should avoid portraying artificial intelligence in an overly optimistic light, instead presenting its actual capabilities alongside its limitations. Moreover, it must be acknowledged that health data are sensitive by nature and, as such, cannot be used for advertising profiling or shared without explicit and informed consent.

References

1. Aggarwal, R., Farag, S., Martin, G., Ashrafian, H. (2021). A Patient Perceptions on Data Sharing and Applying Artificial Intelligence to Health Care Data: Cross-sectional Survey. *Journal of Medical Internet Research, Vol. 23, No. 8*, doi: 10.2196/26162.
2. Albahri, A.S., Duhaim, A.M., Fadhel, M.A., Alnoor, A., Baqer, N.S., Alzubaidi, L., Albahri, O.S., Alamoodi, A.H., Bai, J., Salhi, A., Santamaría, J., Ouyang, Ch., Gupta, A., Gu, Y., Deveci, M. (2023). A systematic review of trustworthy and explainable artificial intelligence in healthcare: Assessment of quality, bias risk, and data fusion. *Information Fusion*, *Vol. 96*, pp. 156-191, https://doi.org/10.1016/j.inffus.2023.03.008.
3. Almeida, F., Junça Silva, A., Lopes, S.L., Braz, I. (2025). Understanding Recruiters' Acceptance of Artificial Intelligence: Insights from the Technology Acceptance Model. *Applied Sciences*, *Vol. 15, No. 2,* 746. https://doi.org/10.3390/app15020746
4. Asan, O., Bayrak, A., Choudhury, A. (2020). Artificial Intelligence and Human Trust in Healthcare: Focus on Clinicians. *Journal of Medical Internet Research*, *Vol. 22, No. 6*, doi: 10.2196/15154.
5. Chen, M., Zhang, B., Cai, Z., Seery, S., Gonzalez, M.J., Ali, N.M., Ren, R., Qiao, Y., Xue, P., Jiang, Y. (2022). Acceptance of clinical artificial intelligence among physicians and medical students: A systematic review with cross-sectional survey. *Frontiers in Medicine, Vol. 9,* doi: 10.3389/fmed.2022.990604.

6. Chen, Y.H. (2025). Exploring the influence of generative artificial intelligence anxiety on problematic ChatGPT use: the fear of missing out and personality traits. *Universal Access in the Information Society.* Retrieved from: https://doi.org/10.1007/s10209-025-01205-7.
7. Gao, S., He, L., Chen, Y., Li, D., Lai, K. (2020). Public Perception of Artificial Intelligence in Medical Care: Content Analysis of Social Media. *Journal of Medical Internet Research, Vol. 22, No.* 7, doi: 10.2196/16649.
8. Hastie, T., Tibshirani, R., Friedman, J. (2009). *The Elements of Statistical Learning*. New York: Springer-Verlag Inc.
9. Hutchesson, M.J., Collins, C.E., Morgan, P.J., Callister, R. (2013). An 8-Week Web-Based Weight Loss Challenge With Celebrity Endorsement and Enhanced Social Support: Observational Study. *Journal of Medical Internet Research, Vol. 15, No. 7,* doi: 10.2196/jmir.2540
10. Jermutus, E., Kneale, D., Thomas, J, Michie, S. (2022). Influences on User Trust in Healthcare Artificial Intelligence: A Systematic Review. *Wellcome Open Research, Vol. 7, 65*, doi: https://doi.org/10.12688/wellcomeopenres.17550.1.
11. Juravle, G., Boudouraki, A., Terziyska, M., Rezlescu, C. (2020). Trust in artificial intelligence for medical diagnoses. *Progress in Brain Research, Vol. 253*, pp. 263-282, *Elsevier.* doi: https://doi.org/10.1016/bs.pbr.2020.06.006.
12. Kelly, S., Kaye, S.A., Oviedo-Trespalacios, O. (2023). What factors contribute to the acceptance of artificial intelligence? A systematic review. *Telematics and Informatics, Vol. 77*, doi: https://doi.org/10.1016/j.tele.2022.101925.
13. Khanijahani, A., Iezadi, A., Dudley, S., Goettler, M., Kroetsch, P., Wise, J. (2022). Organizational, professional, and patient characteristics associated with artificial intelligence adoption in healthcare: A systematic review. *Health Policy and Technology*, *Vol. 11, Iss. 1*, doi: https://doi.org/10.1016/j.hlpt.2022.100602.
14. Khullar, D., Casalino, L.P., Qian, Y., Lu, Y., Krumholz, H.M., Aneja, S. (2022). Perspectives of Patients About Artificial Intelligence in Health Care. *JAMA Network Open. Health Informatics, Vol. 5, No. 5*, doi:10.1001/jamanetworkopen.2022.10309.
15. Nash, M., Thorpe, C., Brown, J.B., Kueper, J.K., Rayner, J., Lizotte D.J., Terry A.L., Zwarenstein, M. (2023). Perceptions of Artificial Intelligence Use in Primary Care: A Qualitative Study with Providers and Staff of Ontario Community Health Centres. *The Journal of the American Board of Family Medicine, Vol. 36, No. 2*, pp. 221-228, doi: 10.3122/jabfm.2022.220177R2.
16. Ochnik, D., Cholewa-Wiktor, M., Jakubiak, M., Pataj, M. (2024). eHealth tools use and mental health: a cross-sectional network analysis in a representative sample. *Scientific reports*, *Vol. 14, No. 1,* 5173. https://doi.org/10.1038/s41598-024-55910-z
17. Robertson, C., Woods, A., Bergstrand, K., Findley, J., Balser, C., Slepian, M.J. (2023). Diverse patients' attitudes towards Artificial Intelligence (AI) in diagnosis. *PLOS Digit Health, Vol. 2, No. 5*, doi: 10.1371/journal.pdig.0000237

18. Schouten, B., Schinkel, M., Boerman, A., van Pijkeren, P., Thodé, M., van Beneden, M., Nannan Panday, R., de Jonge, R., Wiersinga, W., Nanayakkara, P. (2022). Implementing artificial intelligence in clinical practice: a mixed-method study of barriers and facilitators. *Journal Of Medical Artificial Intelligence, Vol. 5*. doi:10.21037/jmai-22-71.
19. Sebastian, G., George, A., Jackson, G. (2023). Persuading Patients Using Rhetoric to Improve Artificial Intelligence Adoption: Experimental Study. *Journal of Medical Internet Research, Vol. 25*, doi: 10.2196/41430
20. Shin, H.S., Callow, M., Farkas, Z.A., Lee, Y.J., Dadvar, S. (2016). Measuring user acceptance of and willingness-to-pay for CVI technology: final research report. *U.S. Department of Transportation.* Retrieved from: https://rosap.ntl.bts.gov/view/dot/31468.
21. Sides, T., Farrell, T., Kbaier, D. (2023). Understanding the Acceptance of Artificial Intelligence in Primary Care. *Communications in Computer and Information Science, Vol. 1832*. Springer, doi: https://doi.org/10.1007/978-3-031-35989-7_65
22. Tucci, V., Saary, J., Doyle, T. (2021). Factors influencing trust in medical artificial intelligence for healthcare professionals: a narrative review. *Journal Of Medical Artificial Intelligence, 5*. doi:10.21037/jmai-21-25.
23. Wang, B., Asan, O., Mansouri, M. (2023). What May Impact Trustworthiness of AI in Digital Healthcare: Discussion from Patients' Viewpoint. *Proceedings of the International Symposium on Human Factors and Ergonomics in Health Care*, *Vol. 12, No. 1,* pp. 5-10, doi: https://doi.org/10.1177/2327857923121001.
24. Wang, Ch.Ch., Lo, S-K., Fang, W. (2008). Extending the technology acceptance model to mobile telecommunication innovation: The existence of network externalities. *Journal of Consumer Behaviour. An International Research Review, Vol. 7, No. 2*, pp. 101-110, doi.org/10.1002/cb.240.
25. Wang, W., Siau, K.L. (2018). Trusting Artificial Intelligence in Healthcare. *Americas Conference on Information Systems*.
26. Wind, A., Vries, S.D., Constantinides, E. (2019). *Marketing a transparent Artificial Intelligence (AI): A preliminary study on message design.* 18th International Marketing Trends Conference-Venice, Italy.
27. Zhang, J., Zhang, Z. (2023). Ethics and governance of trustworthy medical artificial intelligence. *BMC Medical Informatics and Decision Making, Vol. 23, No. 7,* doi*:* https://doi.org/10.1186/s12911-023-02103-9.
28. Zhang, Z., Genc, Y., Xing, A., Wang, D., Fan, X., Citardi, D. (2020). Lay individuals' perceptions of artificial intelligence (AI)-empowered healthcare systems. *Proceedings of the Association for Information Science and Technology. Vol. 57, No. 1* doi: https://doi.org/10.1002/pra2.326.

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WHOLENESS IN TEAL ORGANIZATIONS: QUALITATIVE RESEARCH RESULTS

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Purpose: This article aims to analyze the concept of wholeness in teal organizations and the methods used to define it in the literature.
Methodology: The study employs a qualitative research design, incorporating narrative review with critical analysis, and utilizes an in-depth, semi-structured interview technique, with a total of seven interviews conducted.
Findings: The literature reveals two primary approaches to interpreting wholeness: as an opportunity for self-fulfillment in the workplace, and as an authentic expression of oneself, one's emotions, and opinions. It seems that clarification of this term is necessary. Substantial similarities were observed between initiatives aimed at fostering wholeness and those designed to enhance well-being.
Research limitations/implications: The study's limitations primarily concern the sample size used in the qualitative research, as only seven interviews were conducted. The chosen qualitative research design precludes generalization to the broader population. It would be advisable to continue the research by selecting a larger sample and including a quantitative approach.
Practical implications: Further empirical research on wholeness in teal organizations is warranted. Future studies could address key issues, such as developing a reliable questionnaire to measure wholeness that meets the psychometric properties of a test (standardization, reliability, validity, normalization). In addition, experimental studies should be conducted to evaluate the effectiveness of programs designed to foster wholeness.
Originality/value: This study represents the first attempt to analyze wholeness in teal organizations through a qualitative research lens, thereby addressing a gap in the existing literature.
Keywords: teal organizations, wholeness, self-management, management, wellbeing.
Category of the paper: Research paper.

1. Introduction

Teal organizations put self-management into practice (Ziębicki, 2017). F. Laloux, a key proponent of this idea (Borowiecki, Olesiński, 2020), identifies three fundamental pillars – also referred to as breakthroughs – characteristic of teal organizations in his monograph *Reinventing Organizations*:

- self-management,
- wholeness,
- evolutionary purpose (Laloux, 2015).

According to the *2020 Deloitte Global Human Capital Trends* report, there is a growing emphasis on supporting – and even prioritizing – employee well-being in organizations. Financial data for 2019 indicates that, on average, large U.S. companies spent $3.6 million on well-being programs (Deloitte Development LLC, 2020). Nonetheless, initiatives aimed at fostering wholeness in teal organizations show certain similarities to well-being programs. Therefore, this study explores the concept of wholeness and the effectiveness of organizational interventions introduced under this pillar. An in-depth exploration of the aforementioned aspect allows for the identification of a research gap. In the academic literature, wholeness as a pillar of the concept of teal organizations has not been extensively analysed, which renders this study innovative. It seeks to address the following research questions: How is wholeness defined in the academic literature? How do leaders of teal organizations perceive wholeness? How is it practiced in the organizations studied? The assumptions of this pillar are critically examined in relation to the broader literature.

2. Definition of wholeness in teal organizations

Laloux (2015, p. 72) defines *wholeness* as authentic self-expression, bringing "everything we are" to work. According to the author of *Reinventing Organizations*, organizations have traditionally glorified the assertive nature of human behavior based on logical premises, depreciating intuition, as well as the spiritual and emotional dimensions integral to it.

To examine the concept of wholeness, a narrative review was conducted (Łaguna et al., 2017), utilizing the EBSCO, Google Scholar, and CeON databases. Literature was searched between 2015 and 2024 using the following keywords: *wholeness in teal organization*, *teal organization*, *teal management*. Ultimately, fifty publications – both empirical (predominantly qualitative research) and theoretical – were included in the analysis. Despite the fact that wholeness represents a significant breakthrough in the concept of teal organizations, this issue was not addressed in every article analyzed (out of the 50 reviewed) (Fałda, Małkowska, 2023;

Olesiński, 2018; Powichrowska, 2018; Rezmer, 2020). At the same time, wholeness, together with self-management and evolutionary purpose, is, according to Laloux (2015, p. 72), one of the foundations of the concept of teal organizations. Interestingly, A.J. Blikle devotes a significant portion of his publication to describing wholeness practices, which focus on improving communication and developing emotional intelligence within the organization (Blikle, 2016). Only one empirical study carried out using a quantitative approach took into account the dimension of wholeness by including questions covering this issue in the questionnaire (Buisine, Davies, 2023). In contrast, another publication, based on a case study employing a qualitative approach, has given the dimension of wholeness fuller consideration (Kułaga, Trzcionka, 2019).

The vast majority of papers, however, discuss wholeness – the second breakthrough in teal organizations – solely in theoretical terms, without addressing its practical application, namely the development of wholeness (Table 1). It is worth noting the recurring statements in them to words: "authenticity", "being yourself at work", "feeling at ease", "holistic", "expressing yourself and your emotions", "not putting on masks at work" (Jędrych, 2020; Mikkonen, 2018; Boguszewska, Motała, Ragin-Skorecka, 2023; Rutkowska, Sulich, 2020; Wyrzykowska, 2020).

The definition of wholeness proposed by Laloux (2015) is not sufficiently precise. Further clarification of this term is required. Two perspectives emerge from the analyses. The first, predominant, defines wholeness through emotional expression, authentic self-expression, and a holistic perception of the human being, while the second highlights self-fulfillment and the ability to influence the development of one's talents.

Table 1.
Overview of definitions of wholeness

Author and date	The way of understanding wholeness
Bańkowska, 2020, p. 5; Janulek, Solarski, 2021, pp. 30-31; Trzcionka, 2020, pp. 146-147	Holistic (seeing the human being including the emotional and psychological aspects).
Buisine, Davies, 2023, pp. 2-3	Organizational innovation, "the pursuit of individual wholeness", emphasizing the role of intuition and spirituality.
Chodyka, Pilarska, 2024, p. 537	Ensuring that employees are free to express themselves (their values and goals) in the workplace.
Chrońska, Fibakiewicz, 2020, p. 95; Janulek, Solarski, 2021, pp. 30-31; Jędrych, 2020, p. 75; Pluta, Witek, 2019, p. 239; Rutkowska, Sulich, 2020, p. 128	Authenticity in the workplace.
Chrońska, Fibakiewicz, 2020, p. 95; Jędrych, 2020, p. 75; Trzcionka, 2020, pp. 146-147; Wzorek, 2019, pp. 80-81	Creating a safe workplace.
Gómez Muñoz et al., 2020, p. 4; Laloux, 2015, p. 72	Emphasizing the integrity of the individual, the organization encourages individuals to "go to the workplace with everything we are".
Kułaga, Trzcionka, pp. 473-474; Łyszkowska, 2023, p. 602	Self-fulfilment, the pursuit of development.
Mikkonen, 2018, p. 14; Boguszewska, Motała, Ragin-Skorecka, 2023, p. 163	The employee has the space to express themselves and their emotions, emphasizing integrity in the expression of their private personality and professional persona.

Cont. table 1.

Rosiński, 2018, p. 253	Having the space to discover oneself and being able to decide one's own development.
Wasiluk, 2022, p. 652	"Sense of being yourself in the workplace".
Wyrzykowska, 2020, p. 128	"A sense that people can be themselves at work (…)".
Wzorek, 2019, pp. 80-81	A sense of freedom in the workplace; the opportunity to realize one's full potential.

Source: own study.

However, most researchers consider wholeness consistently with Laloux's perspective (Gómez Muñoz et al., 2020; Kozina, Pieczonka, 2017; Kułaga, Trzcionka, 2019; Rutkowska, Sulich, 2020; Trzcionka, 2020; Wyrzykowska, 2019).

This discussion takes the perspective of wholeness as the authentic expression of oneself and one's own emotions.

3. Implementing wholeness in teal organizations

Laloux (2015) describes the development of wholeness through various initiatives implemented by the studied companies (Table 2), including the use of coaches' and facilitators' support, community building, participation in so-called 'praise meetings', and conflict resolution within teams.

Notably, only a few practices in teal organizations, such as beginning meetings with a moment of silence or resolving conflicts, directly align with the definition of wholeness. However, it is worth questioning the extent to which the enumerated interventions truly foster genuine self-expression, as many of them (e.g., coaching) are already widely implemented by contemporary organizations.

Together with the popularization and promotion of employees' well-being in the organizational context (Białas, Molek-Winiarska, Pelc, 2023), various initiatives have been applied to improve human well-being in companies (Białas, Molek-Winiarska, Pelc, 2023). The report, entitled: *Wellbeing w praktyce. Wiedza. Praktyka. Inspiracja. Rynek polski w 2021/2022* [Well-being in practice. Knowledge. Practice. Inspiration. Polish Labour Market in 2021/2022] presents case studies on the implementation of well-being programs for employees in several organizations. These support programs include: coaching, a leadership development program, empathy-based communication, self-energy management or mindfulness. Table 2 compares the practices offered by wholeness with the initiatives implemented in those programs. Although the concept of well-being is defined differently from wholeness, those practices promoted in both constructs are similar.

In one of the teal organizations, Heiligenfeld, employees are given the opportunity to practice meditation in the workplace, and nurses employed at Buurtzorg participate in a program to improve health (Laloux, 2015). Are these situations not about enhancing well-being? It is worth posing the question of how the use of particular interventions – such as coaching – will enhance employees' well-being or foster wholeness. How will transparent disclosure of a company's financial situation or showing gratitude within a team contribute to employees' skills related to the authentic expression of emotions? For example, S. Jarmuż and M. Tarasiewicz (2019) consider the effectiveness of business coaching in light of academic research. The authors highlight that most systematic observations have focused on workplace coaching. They identify a potential barrier to validating this coaching tool in the operation of several distinct coaching approaches. It is necessary to compare specific coaching methods with a control group receiving no intervention. Concerns also appear in an attempt to assess the effectiveness of this method (should subjective respondents' declarations be accepted?) (Jarmuż, Tarasiewicz, 2019).

Table 2.
Comparison of initiatives supporting wholeness and well-being enhancement programs

Initiatives to develop wholeness and well-being	
Initiatives undertaken as a part of wholeness in teal organizations	**Initiatives implemented as a part of strengthening employee well-being**
– "Praise meetings" at the ESBZ School to build a sense of community, – Starting meetings by thanking or congratulating employees for their contribution to FAVI, creating a climate of gratitude, – The possibility of using facilitators' support during meetings (creation of a central group of facilitators) in an RHD institution, – Organization of annual events at Sounds True: "Pyjamas Day", "Art Salon" (whose purpose is to showcase employees' interests), starting meetings with a moment of silence to help employees settle into the here and now, – Support from a regional coach at Buurtzorg who assists teams in resolving conflicts and ensures a smooth group process.	– The following initiatives have been implemented at OVHCloud Poland: "Random Coffee" and "Let's Lunch" (meetings with randomly selected employees online for lunch or coffee), online integration activities (quizzes and detective games); implementation of regular employee surveys to assess their needs; two types of meetings – "Coffee Talks" (used to learn about the work of other departments) and inspiration sessions, which provide opportunities to share knowledge and interests, – A program supporting mental and physical well-being at Orange (webinars with experts, establishment of a psychological support team), consultations with a psychologist, a mindfulness course called "Light Head Academy", – Implementation of the "Leadership of the Future" program for team managers at Bank Gospodarstwa Krajowego (modules: managing one's energy, feedback culture, empathy-based communication), – Offering diverse forms of development for BGK employees (body awareness training, coaching).

Source: own study.

Measuring the effectiveness of practices implemented under the concept of wholeness would likely require considering each of these forms separately. It would be useful to design a series of experiments involving employees who receive targeted support to enhance well-being or develop wholeness. The respondents should be divided into two groups: a control group that does not receive support and an experimental group, subjected to interventions. Additionally, both groups should receive questionnaires to measure well-being and wholeness,

and the experimental group, before and after receiving help, to monitor the level of said dispositions.

4. Critical analysis of the assumptions of wholeness in the context of research in psychology

Considering the results of empirical research in psychology, it is necessary to examine whether the assumptions of wholeness are feasible in the workplace and to what extent. For example, according to Laloux (2015, p. 198-199), the ability to identify emotions helps to better understand oneself and others and control the affective aspect, which can ultimately contribute to building a friendly working atmosphere. The organizations he surveyed are described as "pioneering", due to their restructuring of key organizational processes, such as recruitment, employee evaluation, redundancy management, and onboarding. These changes challenged commonly accepted solutions and disrupted the status quo, which is often a source of anxiety (Laloux, 2015).

Admittedly, the definition of wholeness reflects freedom of self-expression and emotional freedom in the workplace (Mikkonen, 2018; Boguszewska, Motała, Ragin-Skorecka, 2023). However, questions arise: does this mean in practice that any person can express any opinion on any subject? In the context of emotional expression, can an employee reveal any emotion in any way? Does the definition of wholeness account for individual differences in personality traits?

Psychological research has shown that suppression of emotions can come at a cost. R.F. Baumeister (2003) researched the self-regulation mechanism. In one experiment, subjects were exposed to a poignant video and then assigned to one of three groups: the first one was instructed to suppress their emotions, the second group was instructed to enhance emotional expression, and the third (control) group was allowed to express their feelings naturally. The next stage assessed the physical strength of the subjects by measuring how long they could squeeze the handle of the exercise machine. It was observed that the subjects who did not need to suppress their emotions (the control group) performed best in the task, as they were able to squeeze the dynamometer the longest. In contrast, those who controlled the intensity (by reinforcing the affect or suppressing it) lost perseverance in the task more quickly (Kahneman, 2012).

It must be emphasized that the defining assumptions of wholeness do not consider individual differences. Jarmuż (2023) highlights that the psychology of individual differences includes issues related to intelligence, temperament, and cognitive styles. Considering the personality dimension in the context of measuring the five personality factors, one might ask whether each person should focus equally on authentic self-expression and emotional freedom.

For example, people with a high degree of neuroticism are characterized by impulsivity, less ability to control drives, and reacting with anxiety.

Agreeableness, on the other hand, is characterized by, among other things, modesty, high trust, and submission. In contrast, the extraversion aspect denotes assertiveness, or the need to seek sensations (Strelau, 2002). When dealing with individuals with varying intensities of personality traits, can we discuss bringing all aspects of their personalities to the workplace equally? Bearing personality factors in mind, one person should instead focus on strengthening self-control, another on developing assertiveness, and another on controlling impulses. People also differ in their disposition toward self-control resources. D. Kahneman (2012) presented the operation of system number 1 (fast, thoughtless) and number 2 (analytical, thoughtful). Among the tasks of the latter is controlling our thoughts and behavior. Kahneman, referring to Baumeister's research, shows that drawing on self-control mechanisms and willpower is exhausting, and experiencing their deficit, we may have to deal with the so-called 'ego depletion' phenomenon. In addition, people undergo cognitive overload on a daily basis, which leads to a greater tendency to behave selfishly or overly judgmentally toward others (Kahneman, 2012). Understanding these mechanisms suggests that the assumptions of wholeness – emphasizing self-expression and emotional freedom – provide a limited perspective on emotions, overlooking individual differences and the impact of various mental states (e.g., cognitive overload or ego depletion).

Another questionable aspect remains the word 'authenticity', which is often referred to by authors when defining wholeness. In the field of psychology, the terms: authenticity (Jongman-Sereno, Leary, 2019) and sense of authenticity (Wypych, 2015) are being developed. Authenticity is defined in the nature of: "behavior consistent with one's true self" (Jongman-Sereno, Leary, 2019), while the sense of authenticity is understood as: "freedom to express feelings and opinions in the presence of one's supervisor and co-workers" (Wypych, 2015, p. 79). K.P. Jongman-Sereno and M.R. Leary (2019), as well as Baumeister (2019), present a skeptical attitude towards the construct of authenticity. First, the academics doubt the existence of only one self. Baumeister, in an interview with T. Witkowski (2021, p. 271), observed that the "authentic self" is often portrayed in a solely positive light, though this need not always be the case. The objections to the construct of "authentic self" also include a methodological dimension (the way it is conceptualized and measured is criticized). For instance, in one study, the indicator used to measure the sense of authenticity was a question about the individual's subjective feelings: *how authentic do you feel in your current job?* (Wypych, 2015, p. 86). It is also questionable whether authentic behavior is always expected, and what implications this has for well-being. According to Jongman-Sereno and Leary (2019), the assumptions of authenticity are quite questionable, and their utility is low.

5. Methods

The study employed a qualitative approach within the interpretive-symbolic paradigm, emphasizing subjective cognition of reality (Ćwiklicki, Urbaniak, 2019). An in-depth, semi-structured interview was used to obtain the data (Gendźwiłł, Stasik, 2012). The choice of qualitative approach seems to be particularly justified when the theory is just emerging, being refined and developed, or when some deficiencies can be identified within it (Czernek, 2015). A cognitive gap was identified in understanding wholeness and its implementation in teal organizations. This identification would not be possible without determining the limits of knowledge (Czakon, Glinka, 2021). Based on this relationship, the research aimed to answer the following questions: How do leaders of teal organizations understand wholeness? How do teal organizations implement wholeness? To answer these questions, seven teal organizations in Poland were selected to participate in the study. Purposive sampling was applied (Czakon, Glinka, 2021), which is justified in the case of small samples in qualitative research. In this context, relying on the researcher's knowledge and experience becomes more accurate (Jabłońska, Sobieraj, 2013). The criteria for including organizations were defined as follows: company size (micro-enterprises of up to nine people were excluded), industry (diversified, consulting firms were excluded), autonomy within the organization (areas of employee freedom and the organizational structure solutions used, as well as decision-making autonomy, were evaluated). Interviews with leaders of teal organizations were conducted online, recorded using a dictaphone, and then transcribed. Meetings with the representatives were held twice.

6. Results

The collected material was analyzed using MAXQDA Analytics Pro, version 24.3.0. Hybrid coding, predominantly deductive (etic), was applied.

Table 3.
The comprehension of wholeness in surveyed organizations

Company name	Respondent	Definition
Bees & Honey	Maciej Żybula	Wholeness as: – Transparency, demonstrated by openly sharing information about the company's financial situation and management processes, – Opportunity to develop your competencies within the organization, – Authentic expression of emotions, revealing one's feelings and creating space to talk about difficulties

Cont. table 3.

HighSolution	Adam Matysiak	Wholeness understood as being oneself at work
Lunar Logic	Paweł Brodziński	"Bringing everything we are to work"
Sanofi Pasteur (The described change in the organization towards teal relates to the period 2013-2018)	Maciej Trybulec	Striving for wholeness understood as "attention and sensitivity to the other person" (M. Trybulec), with respect for the other person's boundaries
SoftwareMill	Magdalena Woźniak	Wholeness as authentic self-expression and the possibility of self-development
SPZOZ Dęblin [Independent Public Health Care Institution in Dęblin]	Urszula Pielacka-Chodoła	Wholeness as: – One of the final stages of the organization's development, – The way the patient is treated
Turkusowe Śniadania [Teal Breakfasts]	Łukasz Solarski	Wholeness defined as self-development.

Source: own study, based on interviews.

The first stage of material exploration focused on creating a code list, which included the definition of key terms, followed by preliminary coding (Czakon, Glinka, 2021). The analysis of the gathered material required several revisits to the data (Czakon, Glinka, 2021).

Based on the analysis (Table 3), it was observed that four institutions defined this pillar in alignment with Laloux's perspective, emphasizing authentic self-expression, emotions, and feelings.

Two of the surveyed organizations interpreted wholeness broadly, encompassing transparency, opportunities for self-development, and authentic self-expression. One institution viewed wholeness through an evolutionary lens.

Further analysis examined how organizations seek to develop wholeness. What practices have they been able to adapt for this purpose (Table 4 and Table 5), and how do they correspond to the definition of wholeness?

Table 4.
Implementing wholeness in the surveyed organizations

Organizations	Wholeness
HighSolution	– Coach's support of team development. – Strengthening mindfulness among employees. – Developing an attitude of compassion among employees and encouraging them to help other employees.
Lunar Logic	– Focusing on developing solutions and practices to limit the development and expression of this pillar. – The prevailing belief that the development of this aspect can cause harm to the organization and the individual.
Sanofi Pasteur (The described change in the organization towards teal relates to the period 2013-2018)	– During weekly meetings, implement practices that relate to the employee well-being question: How are you? How do you start your day? – Nurturing an empathetic approach to the employee. – Appreciating the employee. – Celebrating successes together.

Cont. table 4.

SoftwareMill	– Establishing various thematic channels on Slack (the organization works remotely) to share interests, knowledge, celebrate birthdays, read books together, inspire, create an integral gamification system. – Establishing the role of an angel whose job is to support employees.
Turkusowe Śniadania [Teal Breakfasts]	Implementation of meetings according to the Holacratic scheme; at the beginning and end of meetings, creating space to discuss oneself and one's emotional state while ensuring psychological safety.

Source: own study, based on interviews.

One surveyed company was critical of this teal pillar, as it is focused on restricting wholeness development, as unrestricted emotional expression may harm individuals (Table 4). Four of the organizations created a safe space for team members to express their feelings, emotions, and concerns during meetings. Bees&Honey and SPZOZ Dęblin, an Independent Public Health Care Institution in Dęblin, were by far the most active in adopting initiatives, with these two organizations implementing significantly more than any other institution involved in the study (Table 5).

Table 5.
Comparison of wholeness-related initiatives in two surveyed organizations across selected categories

Category	SPOZ Dęblin [Independent Public Health Care Institution in Dęblin]	Bees & Honey
Role-related	–	– Establishing the role of a teal caregiver. – Creating the "Human Happiness" role. – Establishing the role of circle rep, responsible for the emotional and spiritual development of employees, identifying team tensions, and initiating conversations on the subject (operating partly within the holacratic system). – Support from coaches, who are referred to as teal guardians.
Communication	– Creating an employee idea box (which gives employees the opportunity to speak anonymously on topics related to the organization). – Organizing the so-called "praise meetings" (purpose praise and appreciate person sitting next to you). – Creating a safe work environment where employees feel comfortable speaking out.	– Practicing *Nonviolent Communication* in teams. – Providing positive feedback (building a culture of feedback). – Improving communication skills, assertive messages (avoiding taboo topics concerning the organization). – Focusing on resolving conflicts. – Using *drama class* tools (group techniques for working through tensions), encouraging honesty between coworkers.
Well-being	– Caring for well-being (purchase of electric bicycles for nurses). – Offering workplace yoga sessions.	– Emphasis on developing mindfulness.

Cont. table 5.

Emotional expression	– Encouraging employees to share their feelings: what moved them, delighted them? What made them a better person? – "Organization means development"; encouraging employees to reflect on inspiring texts that have impacted them.	– Starting meetings with a question: What do you start the meeting with on the level of body, emotions, spirit, and thoughts? – Organizing daily meetings, during which a space is created to express gratitude.
Relationship related	– Integration of the team (organization of cyclic trips).	–

Source: own study, based on interviews.

These activities —ranging from establishing roles within the organization that support the development of this pillar (e.g., the role of teal supervisor, rep link, human happiness coordinator), improving communication (such as practicing nonviolent communication, building a culture of feedback), working through tensions and conflicts, cultivating a positive attitude, group activities (yoga etc.), mindfulness, as well as encouraging the expression of opinions and ideas. Table 5 compares initiatives supporting wholeness in the Bees&Honey organization and in SPOZ Dęblin, considering six categories. The majority of activities initiated by both organizations are related to communication and emotional expression.

It is worth rephrasing the question: What is the difference between well-being enhancement activities and implementing wholeness in the surveyed organizations? Most of the activities mentioned in Table 4 and Table 5 are offered in numerous modern organizations as a form of employee development. An excellent example of that is coaching used in business to develop organizations. The same is true of the spread of M.B. Rosenberg's nonviolent communication NVC (Kułaga, Trzcionka, 2019).

7. Discussion

The definition of wholeness remains somewhat imprecise. Qualitative research indicates that representatives of teal organizations possess a nuanced understanding of wholeness, with four organizations defining the term from Laloux's perspective. Literary studies, on the other hand, suggest two interpretations of wholeness: as an opportunity for self-fulfillment in the workplace and as a space for authentic self-expression, including one's feelings and opinions. An analysis of wholeness-related practices suggests that not all activities align directly with its definition. Many such programs (under various names) are in operation in teal organizations, although their effectiveness remains empirically unproven.

Similarities were also observed between wholeness initiatives in teal organizations and well-being programs. Another concern regarding this pillar is its effectiveness. How can we be certain that practices such as meditation, workplace yoga, praise, coaching, and other initiatives

truly foster authentic self-expression and emotional freedom? Additionally, the assumptions of wholeness do not account for individual (personality) differences. Thus, not everyone should be expected to prioritize emotional expression or opinion-sharing equally. The issue of wholeness has not yet been the subject of broader empirical inquiry. The research undertaken can therefore be considered innovative.

It is equally important to acknowledge that the selection of a specific research design involves certain limitations. Qualitative research does not allow for generalization to the entire population. Additionally, it should be emphasized that only seven interviews were conducted with representatives of the teal organization. It would be advisable to continue the research with a larger sample, ideally comprising at least fifteen interviews. This qualitative study can serve as a starting point for an in-depth analysis of this issue.

Developing a reliable construct to accurately define wholeness and operationalize it would be beneficial (Chirkowska-Smolak, 2020). This step would aim to develop a reliable scale to measure the variable under study. Subsequent experimental studies, including control groups, can be planned to test the long-term effectiveness of specific interventions implemented by the organization as part of wholeness. These studies would involve conducting quantitative measurements using questionnaire methods (to assess wholeness) before and after support is applied.

8. Conclusions

The emphasis on employee well-being in modern organizations is increasing, as reflected by the financial expenditures on such initiatives (Deloitte Development LLC, 2020). Programs aimed at developing wholeness and those related to well-being share similarities. However, the effectiveness of these activities remains unverified. Some may be ineffective and expose organizations to unnecessary costs. A critical analysis of wholeness enables a more precise definition of its terminology and a reassessment of its underlying assumptions.

The conducted research revealed that participants describe wholeness as authentic self-expression, the expression of emotions, opportunities for self-development, bringing one's self to work, and transparency. Based on these findings, a working (narrow) definition of the term may be proposed. **Wholeness is understood as authentic self-expression, manifested through the ability to express emotions in the workplace, share personal feelings, and voice one's opinions.**

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References

1. Akberdiyeva, A. (2018). Identyfikacja korzyści z funkcjonowania organizacji w warunkach turkusowego modelu zarządzania. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu*, *543*, 9-23. http://dx.doi.org/10.15611/pn.2018.543.01
2. Bańkowska, M. (2020). Od bursztynu do turkusu – perspektywy przeobrażeń systemów zarządzania bibliotekami w świetle doświadczeń uczelni zawodowych. *Nowa Biblioteka* (*Usługi, Technologie Informacyjne i Media*), *2(37),* 1-18. https://doi.org/10.31261/NB.2020.37.08
3. Baumeister, R.F. (2003). Ego Depletion and Self-Regulation Failure: A Resource Model of Self-Control. *Alcoholism Clinical and Experimental Research*, *27(2),* 281-283. https://doi.org/10.1097/01.ALC.0000060879.61384.A4
4. Baumeister, R.F. (2019). Stalking the True Self Through the Jungles of Authenticity: Problems, Contradictions, Inconsistencies, Disturbing Findings—and a Possible Way Forward. *Review of General Psychology*, *23(1),* 143-154. https://doi.org/10.1177/1089268019829472
5. Białas, S., Molek-Winiarska, D., Pelc, A. (2023). Kultura organizacyjna sprzyjająca poprawie dobrostanu pracowników. *Zarządzanie Zasobami Ludzkimi, 150(1),* 73-93. https://doi.org/10.5604/01.3001.0016.2926
6. Blikle, A. J. (2018). *Doktryna jakości. Wydanie II turkusowe. Rzecz o turkusowej organizacji*. Onepress, pp. 65-68, 122-124.
7. Boguszewska, K., Motała, D., Ragin-Skorecka, K. (2023). Pokolenie Z nie jest gotowe na pracę w turkusie. *Zeszyty Naukowe Politechniki Poznańskiej*, *87*, 161-183. Retrieved from: https://sin.put.poznan.pl/publications/details/i56064, 10.05.2025.
8. Bojar, E., Bojar, M. (2020). Lider w organizacji turkusowej. In: Z. Olesiński (Ed.), *Składniki turkusowych organizacji* (pp. 28-37). Difin.
9. Bondarouk, T., Bos-Nehles, A., Renkema, M., Meijerink, J. (2018). *Organisational Roadmap Towards Teal Organisations*. Advanced Series in Management. Retrieved from: https://www.researchgate.net/publication/326466147_Organisational_Roadmap_Towards_Teal_Organisations, 02.02.2024.

10. Borowiecki, R., Olesiński, Z. (2019). Uwarunkowania kreacji turkusowych organizacji w Polsce. *Zarządzanie organizacjami*, *10*, 11-17. http://dx.doi.org/10.33141/po.2019.10.02
11. Borowiecki, R., Olesiński, Z. (2020). Próba konceptualizacji uwarunkowań turkusowych organizacji. In: Z. Olesiński (Ed.), *Składniki turkusowych organizacji* (pp. 17-27). Difin.
12. Buisine, S., Davies, M. (2023). Can Teal practices increase employees' work engagement? *European Conference on Management Leadership and Governance*, *19(1),* 96-105. https://doi.org/10.34190/ecmlg.19.1.1662
13. Chirkowska-Smolak, T. (2020). Psychologiczna diagnoza zachowań i zjawisk w organizacji. In: B. Rożnowski, P. Fortuna (Eds.), *Psychologia biznesu* (pp. 31-49). PWN.
14. Chodyka, M., Pilarska, J. (2024). Impact Of Turquoise Management on Interdisciplinarity in IT Project Management. *Economic and Regional Studies*, *17(3),* pp. 532-548. https://doi.org/10.2478/ers-2024-0029
15. Chrońska, M., Fibakiewicz, K. (2020). Samozarządzanie we współczesnych organizacjach – koncepcja organizacji turkusowej. In: E. Śnieżek (Ed.), *Trendy w biznesie* (pp. 91-101). SIZ.
16. Czakon, W., Glinka, B. (2021). *Podstawy badań jakościowych*. PWE, pp. 23, 121-33.
17. Czernek, K. (2015). Wprowadzenie do badań jakościowych w naukach o zarządzaniu. In: W. Czakon (Ed.), *Podstawy metodologii badań w naukach o zarządzaniu* (pp. 170-171). Oficyna Wolters Kluwer Business.
18. Ćwiklicki, M., Urbaniak, A. (2019). *Studium przypadku w naukach o zarządzaniu*. Wydawnictwo Uniwersytetu Ekonomicznego w Krakowie, pp. 18-20.
19. Deloitte Development LLC (2020). *The social enterprise at work: Paradox as a path forward* (2020 Deloitte Global Human Capital Trends). Retrieved from: https://mkto.deloitte.com/rs/712-CNF-326/images/tech-sap-global-human-capital-trends.pdf, 03.04.2025.
20. Fałda, B., Małkowska, M.A. (2023). Turkusowa forma zarządzania w organizacjach opartych na wiedzy. *Studia Ekonomiczne i Regionalne, 1(16),* 51-64. Retrieved from: https://ageconsearch.umn.edu/record/339227/files/pdf-155166-88760.pdf, 10.05.2025.
21. Gendźwiłł, A., Stasik, A. (2012). Projektowanie badania jakościowego. In: D. Jemielniak (Ed.), *Badania jakościowe. Podejścia i teoria* (pp. 1-22). PWN.
22. Gómez Muñoz, C.F., Jain, A.K., Romero, A.M., Ruiz, M.A., Uruburu, Á. (2020). The Path towards Evolutionary—Teal Organizations: A Relationship Trigger on Collaborative Platforms. *Sustainability*, *12(23),* 1-17. http://dx.doi.org/10.3390/su12239817
23. Holwek, J. (2018). Dajmy już spokój z tym turkusem. O tym, jak piękna praktyka staje się modą, a nawet ideologią. *Coaching Review*, *1(10),* 11-30. Retrieved from: https://repozytorium.kozminski.edu.pl/pub/5006, 10.05.2025.
24. Hopej-Tomaszycka, M., Hopej, M. (2018). Struktury organizacyjne turkusowych organizacji. *Zeszyty Naukowe. Organizacja i Zarządzanie*, *130*, 233-242. Retrieved from: https://bibliotekanauki.pl/articles/321312, 10.05.2025.

25. Iwko, J., Pisarska, S. (2018). Human Resources Management in a Teal Organization Based on the Example of Brewa c.c. in Kalisz. *Annales Universitatis Mariae Curie-Skłodowska Lublin – Polonia*, *6(52),* 79-86. http://dx.doi.org/10.17951/h.2018.52.6.79-86
26. Jabłońska, K., Sobieraj, A. (2013). Metodyka dobierania próby badawczej. *Bezpieczeństwo i Technika Pożarnicza*, *32(4),* 31-26. https://doi.org/10.12845/bitp.32.4.2013.3
27. Jack, R. (2018). Building Teal Organizations with Servant Leadership? In: D. van Dierendonck, K. Patterson (Eds.), *Practicing Servant Leadership Developments in Implementation*. Palgrave Macmillan, pp. 187-207.
28. Janulek, P., Solarski, Ł. (2021). *Turkusowa ewolucja. O organizacji, w której Ty sam chciałbyś wzrastać*. Wydawnictwo Nauki i Rozwoju, pp. 30-31.
29. Jarmuż, S. (2023). *Czy mądrości można się nauczyć?* PWN, p. 127.
30. Jarmuż, S., Tarasiewicz, M. (2019). *Alfabet mitów menedżerskich czyli o pułapkach bezrefleksyjnego działania*. Gdańskie Wydawnictwo Psychologiczne, pp. 71-80.
31. Jeznach, A. (2017). *Szef, który ma czas. Ewolucja zarządzania-dziennik budowy turkusowej firmy*. Onepress, pp. 11-70.
32. Jędrych, E. (2020). Zarządzanie pracownikami w turkusowych organizacjach. In: Z. Olesiński (Ed.), *Składniki turkusowych organizacji* (pp. 69-94). Difin.
33. Jongman-Sereno, K.P., Leary, M.R. (2019). The Enigma of Being Yourself: A Critical Examination of the Concept of Authenticity. *Review of General Psychology, 23(1),* 133-142. https://doi.org/10.1037/gpr0000157
34. Juchnowicz, M. (2016). Firmy samoangażujące – utopia czy biznesowy realizm. *Zarządzanie i finanse*, *2(14),* 171-181. Retrieved from: https://bibliotekanauki.pl/chapters/19090918, 10.05.2025.
35. Kahneman, D. (2012). *Pułapki myślenia. O myśleniu szybkim i wolnym*. Media Rodzina, pp. 58-59.
36. Kowalczyk, L. (2022). Turkusowa organizacja odpowiedzią na wyzwania współczesności – relacji i interdyscyplinarności. Perspektywa Turkusowej Organizacji w zarządzaniu. *Prace Naukowe Wyższej Szkoły Zarządzania i Przedsiębiorczości z siedzibą w Wałbrzychu*, *52(2),* 119-147. Retrieved from: https://pracenaukowe.wwszip.pl/prace/PN_52.pdf, 10.05.2025.
37. Kozina, A., Pieczonka, A. (2017). Negocjacje w turkusowej organizacji. *Zarządzanie i finanse*, *2(15),* 163-176. Retrieved from: https://bazekon.uek.krakow.pl/zeszyty/171512832, 10.05.2025.
38. Kułaga, M., Trzcionka, M. (2019). Granice wyobrażone i rzeczywiste – ewolucja i transgresja. Zmiana paradygmatu funkcjonowania organizacji na przykładzie krakowskiej organizacji Leance. *Politeja*, *1(58),* 465-492. https://doi.org/10.12797/Politeja.16.2019.58.25
39. Laloux, F. (2015). *Pracować inaczej*. Studio EMKA, pp. 72-73, 195-298.

40. Łaguna, M., Mazur, Z., Orłowska, A. (2017). Systematyczny przegląd literatury: Na czym polega i czym różni się od innych przeglądów. *Ogrody Nauk i Sztuk*, *7*, 352-353. Retrieved from: https://www.researchgate.net/publication/322086591_Systematyczny_przeglad_literatury_Na_czym_polega_i_czym_rozni_sie_od_innych_przegladow, 10.05.2025.
41. Łyszkowska, E. (2023). Organizacje turkusowe w Polsce, charakterystyka, efektywność i reakcja na sytuacje kryzysowe. *The Prison Systems Review*, *4(121),* 597-614. https://orcid.org/0000-0001-8427-7549
42. Mazilu, C.E., Dobrescu, R. (29-30.10.2020). *Increasing Autonomy In Health Care Management With Teal Organizations*. 2020 International Conference on e-Health and Bioengineering. Institute of Electrical and Electronics Engineers.
43. Mikkonen, M.R. (2018). *What Does it Take for a Startup Company to be a "Teal" Organisation? Case: Yogaia* (Bachelor Dissertation). Helsinki Metropolia University of Applied Sciences, European management. Retrieved from: https://urn.fi/URN:NBN:fi:amk-2018052810760, 10.05.2025.
44. Olesiński, Z. (2018). Samozarządzanie jako metoda zarządzania zespołami projektowymi. *Zeszyty Naukowe Wydziału Informatycznych Technik Zarządzania Wyższej Szkoły Informatyki Stosowanej i Zarządzania*, *1*, 21-36. Retrieved from: https://www.wit.edu.pl/dokumenty/wydawnictwa_naukowe/zeszyty-naukowe-WPZ/2018-1/001_2-Z-Olesi%C5%84ski.pdf, 10.05.2025.
45. Olesiński, Z. (2020). W dążeniu ku turkusowej organizacji. In: Z. Olesiński (Ed.), *Składniki turkusowych organizacji* (pp. 264-274). Difin.
46. Pluta, A., Witek, J. (2019). Możliwość wdrożenia turkusowych miejsc pracy we współczesnych organizacjach – próba oceny. *Przedsiębiorczość i Zarządzanie*, *XX(10),* 233-246. Retrieved from: https://www.researchgate.net/publication/335791246_Mozliwosc_wdrozenia_turkusowych_miejsc_pracy_we_wspolczesnych_organizacjach_-proba_oceny_The_Possibility_of_Introducing_the_Turquoise_Workplaces_in_Contemporary_Organizations_-_an_Assessment_Attempt, 10.05.2025.
47. Powichrowska, B. (2018). Od zarządzania wiedzą do zarządzania w kolorze turkusu. *Przedsiębiorstwo & Finanse*, *1*, 95-104. Retrieved from: https://cejsh.icm.edu.pl/cejsh/element/bwmeta1.element.desklight-c2a65d4e-37ab-4720-a1fb-859b25482886, 10.05.2025.
48. Rezmer, K. (2020). Organizacja turkusowa – wielka pomyłka czy wspaniałe rozwiązanie? In: M. Bogusz, M. Wojcieszak, P. Rachwał (Eds.), *Poszerzamy Horyzonty* (pp. 177-185). Mateusz Weiland Network Solutions.
49. Rosiński, J. (2018). Creating an Evolutionary Teal Organization on a Step-by-step Basis. A Case Study. *Przedsiębiorczość i zarządzanie*, *6(19),* 243–256. Retrieved from: https://ruj.uj.edu.pl/server/api/core/bitstreams/943657f5-3c77-41e9-b5c5-a7a8ea9b58bb/content, 10.05.2025.

50. Rutkowska, M., Sulich, A. (2020). Zielony a turkusowy styl zarządzania. *Zarządzanie publiczne*, *1(49),* 15-31. Retrieved from: https://www.academia.edu/110590068/Zielony_a_turkusowy_styl_zarz%C4%85dzania
51. Rzepka, A. (2020). Turkusowe organizacje w Gruzji. In: Z. Olesiński (Ed.), *Składniki turkusowych organizacji* (pp. 313-326). Difin.
52. Rzepka, A. (2021). Teal organizations in times of industry 4.0. *European Research Studies Journal*, *24(Special Issue 1),* 60-71. Retrieved from: https://www.researchgate.net/publication/352336220_TEAL_Organizations_in_Times_of_Industry_40, 10.05.2025.
53. Strelau, J. (2002*). Psychologia różnic indywidualnych*. Wydawnictwo Naukowe Scholar.
54. Trzcionka, M. (2020). Turkusowa organizacja: żywy organizm. In: M. Geise, J. Oczki, D. Piotrowski (Eds.), *Wybrane aspekty przemian gospodarczych w Polsce* (pp. 138-160). Wydawnictwo Uniwersytetu Kazimierza Wielkiego.
55. Wasiluk, A. (2022). On the way to turquoise organizations and turquoise leadership. *Organization and Management Series*, *158*, 647-661. http://dx.doi.org/10.29119/1641-3466.2022.158.42
56. Wiench, P. (2020). Uspołecznienie zarządzania. Organizacje turkusowe i demokratyzacja podejmowania decyzji. In: Z. Olesiński (Ed.), *Składniki turkusowych organizacji* (pp. 208-220). Difin.
57. Witkowski, T., Baumeister, R.F. (2021). *Giganci psychologii. Rozmowy na miarę XXI wieku*. Wydawnictwo Bez Maski, p. 271.
58. Wypych, M. (2015). Poczucie autentyczności jako czynnik wpływający na zaangażowanie pracowników. *Zeszyty Naukowe UEK*, *8(944),* 79-89. https://doi.org/10.15678/ZNUEK.2015.0944.0807
59. Wyrzykowska, B. (2019). Teal organizations: literature review and future research directions. *Central European Management Journal*, *27(4),* 124-141. https://doi.org/10.7206/cemj.2658-0845.12
60. Ziębicki, B. (2017). Organizacje bez „szefów" – współczesna moda czy nowy paradygmat zarządzania? *Humanizacja pracy*, *4(290),* 76-91. Retrieved from: https://www.humanizacja-pracy.pl/witryna/doc/Humanizacja%204%202017.pdf, 10.05.2025.

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CHATGPT AS A TOOL IN HIGHER EDUCATION – ANALYSIS OF STUDENT UTILIZATION AND PERCEPTION

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Purpose: The purpose of this paper is to explore how students at the Faculty of Management at the University of Gdańsk use ChatGPT, a generative AI tool, for academic purposes. The study focuses on their motivations, perceptions, and overall attitudes toward the tool in the context of higher education.
Design/methodology/approach: The research combines a literature review with empirical findings from a survey conducted among 260 students. This mixed-method approach allows for an in-depth analysis of how ChatGPT is applied in academic settings.
Findings: The findings indicate that ChatGPT is widely used for tasks such as quick information retrieval, writing assistance, and idea refinement. Students primarily value its efficiency and the potential to improve the quality of their work. However, concerns were also raised regarding the reliability of content, and its possible negative impact on creativity and critical thinking.
Research limitations/implications: The study is limited to one faculty and one institution, which may affect the generalizability of the findings. Future research should consider a broader sample across various academic disciplines and institutions.
Practical implications: The results highlight the need for structured educational programs that support students in the responsible and ethical use of AI tools. Institutions of higher education could use these insights to develop policies and guidelines that foster thoughtful and informed integration of AI into academic practice.
Social implications: This research contributes to the ongoing discussion about the societal impact of AI in education. By addressing students' concerns and behaviors, it encourages a more reflective approach to the use of generative AI and can inform future strategies for its ethical implementation.
Originality/value: This paper offers a unique perspective on student interaction with generative AI, supported by empirical data. It adds value to the academic discourse by providing actionable insights for both researchers and practitioners interested in the evolving role of AI in higher education.
Keywords: chatGPT, higher education, AI tools, generative artificial intelligence, student perception.
Category of the paper: research paper.

1. Introduction

Artificial intelligence (AI) plays an increasingly significant role in academic education, offering new opportunities for both students and educators. These include quick information retrieval, improved understanding of complex topics, and the personalization of the learning process. However, integrating AI into education also introduces risks, such as limiting the development of critical thinking and creativity. Among various AI tools, Chat GPT, developed by OpenAI, has emerged as a prominent language model capable of generating human-like text based on prompts. ChatGPT holds significant potential for broad application in education, offering functionalities such as text generation, question answering, and language translation. This can result in both beneficial and adverse consequences (Kasneci et al., 2023; Gimpel et al., 2023). Even before the widespread adoption of ChatGPT, higher education had become a crucial area for the implementation of such technologies (Al Muid et al., 2021).

This article adopts a theoretical and empirical perspective, emphasizing the transformative potential of AI tools in education. It aims to provide a balanced understanding of how ChatGPT and similar technologies can enhance the learning process. At the same time, it acknowledges the risks, including ethical dilemmas, potential over-reliance, and challenges. By grounding this analysis in a review of current literature and practical applications, the article highlights the dual-edged nature of AI in education. The first part of this article reviews literature on generative AI in higher education. The second part presents findings from study conducted at the University of Gdańsk, analyzing student utilization and perceptions of ChatGPT. Despite significant interest in this area among researchers, the topic remains relatively new and rapidly evolving. There is still a notable research gap regarding long-term implications of using generative AI in education.

2. Artificial Intelligence and ChatGPT in Higher Education

2.1. Foundations of Artificial Intelligence

Artificial intelligence (AI) has rapidly advanced, particularly in the digital era accelerated by the Covid-19 pandemic. The journey began in 1950 with A.M. Turing, who designed Turing Test, to evaluate whether a machine could mimic human-like intelligence through natural language communication (Turing, 1950). Despite decades of attempts, most AI systems failed this test. However, in 2024, researchers from the Stanford School of Humanities and Science conducted studies confirming that the latest version of ChatGPT, namely ChatGPT-4, operates in a manner consistent with human behaviour, with the distinction of exhibiting significantly more altruistic and cooperative behaviour (Jackson et al., 2024).

Definitions of AI vary widely. McCarthy described it as the science and engineering of creating intelligent machines (McCarthy, 2007). Since then, many definitions have emerged, emphasizing aspects such as learning (Castelvecchi, 2016) and the ability to mimic human skills and competencies (Brynjolfsson et al., 2017). Currently, the literature on research in this field presents various perspectives and definitions depending on the areas of study. There is still no single, universally agreed-upon definition of artificial intelligence. As Jiang et al. (2022) have noted, artificial intelligence has permeated our daily lives and begun to play a transformative role in areas such as education, transportation, industry, healthcare, and many others. AI has become a significant factor in driving socio-economic changes globally and has contributed to the rapid development of modern technologies that support scientific research across various fields. According to Gams et al. "artificial intelligence, also known as machine intelligence, is the intelligence demonstrated by machines as opposed to the natural intelligence exhibited by humans and other animals. Artificial intelligence, therefore, performs human cognitive functions such as perception, processing of input data from the environment, and learning" (Gams et al., 2019). Berente et al. proposed define AI „as the frontier of computational advancements that references human intelligence in addressing ever more complex decision-making problems" (Berente et al., 2021, Engström et al., 2024). The authors indicate that they perceive intelligence more as a process rather than a phenomenon. Sheikh et al. (2023) add that, in its most precise definition, AI represents the replication of human intelligence by computers.

2.2. ChatGPT in Education Context

Generative artificial intelligence (Generative AI) is increasingly gaining significance in both various industrial sectors and education. According to the definition provided by Feuerriegel et al., generative AI refers to computational techniques capable of creating new, meaningful content, such as text, images, or audio, based on provided training data. Examples of such tools include Copilot, DALL-E, and ChatGPT (Feuerriegel et al., 2024).

ChatGPT operates as a conversational agent that employs large language models (LLMs). The acronym GPT stands for Generative Pre-Trained Transformer, representing a series of language models created by OpenAI and trained on extensive datasets sourced from the Internet (Gimpel et al., 2023). This cutting-edge technology, quickly gained a huge number of users, exceeding one million in the first week (Caldarini et al., 2022; Farhi et al., 2023). The term "conversational agent" refers to software that utilizes natural language to interact with users, either textually (as chatbots) or vocally (as virtual assistants) (Gimpel et al., 2023; McTear et al., 2016). Dwivedi et al., point out that an AI tool such as ChatGPT generates texts that cannot be distinguished from text written by a human (Dwivedi et al., 2023).

ChatGPT, as a tool utilized by participants in higher education, offers substantial capabilities. For students, it can become an indispensable resource due to its numerous advantages: it is user-friendly and accessible, and it possesses broad applicability across various

academic disciplines. This makes it highly valuable for a range of tasks such as language translation, grammatical correction, writing assignments, calculations, text summarization, and explanation. Conversely, this tool can also aid lecturers in managing written work, generating ideas for exercises, creating presentations, and identifying discussion topics for classes. Furthermore, it can serve as support for research and administrative tasks (Atlas, 2023; Gimpel et al., 2023). According to Kasneci et al. (2023), large language models like ChatGPT in higher education enhance the process of generating summaries and outlines, enabling students to swiftly apprehend core concepts and systematically structure their writing. Furthermore, they play a significant role in advancing research skills by offering comprehensive information and resources on designated topics, identifying underexplored areas, and pointing out prevailing research trends. This support aids students in achieving a more profound understanding and critical analysis of the subject matter.

The use of ChatGPT enhances productivity and student life satisfaction by providing comprehensible and relevant answers. However, limitations related to response bias, limited knowledge, and lack of emotional intelligence pose significant challenges to building trust and student engagement (Rehman et al., 2024). Another challenge concerns academic integrity, including plagiarism and cheating, emphasizing the need for institutions to develop guidelines for the ethical use of AI in education (Rejeb et al., 2024). Cotton et al. (2024) highlight concrete cases of plagiarism and academic dishonesty involving ChatGPT, emphasizing that such tools can be easily misused as a form of contract cheating. This poses serious challenges for maintaining integrity in academic assessment. Their findings underline the urgency of developing clear policies and student guidance on the ethical boundaries of AI use in academic work. In the interest of education, it is crucial to integrate ChatGPT rapidly into teaching processes, educate students on its proper usage, and prepare them for a future involving AI technologies (Mennella, 2024).

The Technology Acceptance Model (TAM), developed by Davis (1989), posits that two key factors — perceived usefulness and perceived ease of use — determine users' acceptance of new technologies. In the context of AI tools such as ChatGPT, these dimensions play a crucial role in shaping students' attitudes and intentions to adopt such tools in educational settings. Almogren et al. (2024) applied TAM to the case of ChatGPT and found that perceived ease of use and usefulness significantly influence positive user attitudes, while factors such as feedback quality, evaluation practices, and social norms further affect students' intention to use the tool. Similary, Rejeb et al. (2024), using web mining and natural language processing (NLP) techniques, highlight that ChatGPT is a vital educational tool supporting dynamic and interactive learning environments. Furthermore, Shloul et al. (2024) assessed the impact of activity-based teaching and the use of ChatGPT on students' academic performance. Their findings show that activity-based teaching increases engagement, motivation, and critical thinking skills, leading to better academic outcomes. Additionally, the integration of ChatGPT

supports active learning by offering new opportunities for interactive learning and personalized assistance, aiding in the understanding and exploration of complex concepts.

In Table 1, the findings of selected studies on the role of ChatGPT in education are summarized, highlighting its benefits and challenges. ChatGPT has been shown to enhance productivity, communication skills, programming comprehension, critical thinking, and academic performance. It also offers personalized support, fostering engagement and satisfaction among students. However, challenges such as ethical concerns, trust issues, and the need for clear usage guidelines remain. Factors like perceived usefulness, ease of use, and social influence affect its adoption, while cultural and personal factors, including morality and religion, shape attitudes toward the tool. Research on ChatGPT in higher education spans countries such as the United Arab Emirates, Peru, Saudi Arabia, Vietnam, and Norway, reflecting its global relevance.

Table 1.
Summary of studies on ChatGPT in education

Authors	**Year**	**Country**	**Sample Size**	**Key Findings**
Farhi et al.	2023	United Arab Emirates	388	ChatGPT transforms education, enhancing productivity and creativity, but raises ethical and dependency concerns. Students in the UAE highlight its potential and risks, urging clear guidelines to balance innovation and integrity.
Ngo	2023	Vietnam	200	Students appreciate ChatGPT's ability to save time and offer personalized tutoring, enhancing academic engagement. However, concerns about source reliability, ethical usage, and the need for clear usage guidelines remain pivotal for its adoption.
Singh et al.	2023	United Kingdom	430	High awareness of ChatGPT exists among students, yet its academic use remains limited. Concerns about ethical usage and unclear university policies highlight the need for explicit guidelines and integration into educational frameworks.
Acosta-Enriquez et al.	2024	Peru	595	Cognitive and affective components significantly shape attitudes toward ChatGPT among students. Behavioral intentions arise from cognitive beliefs and emotional responses, while gender and age exhibit minimal moderating effects.
Rehman et al.	2024	Saudi Arabia	305	ChatGPT improves productivity, engagement, and academic satisfaction by enhancing accessibility and supporting unique learning experiences. However, trust concerns arise due to biases, limited emotional intelligence, and incomplete knowledge.
Jalon et al.	2024	Philippines	82	ChatGPT aids Python programming learning by enhancing comprehension, efficiency, and student satisfaction. However, it shows limitations with complex tasks. No significant exam score differences were found between users and non-users, promoting balanced adoption.

Cont. table 1.

Sundkvist, Kulset	2024	Norway	99	ChatGPT is perceived as useful and trusted for academic purposes, particularly for course-specific questions. However, social influence and trust issues affect its adoption, especially in accounting contexts, with varied acceptance across disciplines.
Chellappa, Luximon	2024	India	149	Design students find ChatGPT engaging and easy to use, appreciating its capabilities for generating ideas and learning. However, UXD students struggle with prompt formulation, highlighting the need for tailored educational integration.
Elbaz et al.	2024	Oman	312	ChatGPT adoption enhances academic performance among business students, driven by perceived usefulness and ease of use. Personal morality and religion-based ethics moderate its use, emphasizing the need for ethical guidelines.
Youssef et al.	2024	United Arab Emirates	353	ChatGPT significantly enhances student engagement, critical thinking, and academic achievement by providing personalized, interactive support. Its integration into education fosters motivation and promotes deeper learning among students in UAE universities.

Source: author's own compilation from multiple studies.

The use of ChatGPT by students is an emerging area of research, gaining increasing attention among academics who encounter this technology both as educators and researchers. Although some aspects have been explored, further analysis is needed to understand how acceptance and perception may evolve over time and how cultural contexts influence its integration into education.

3. Materials and methods

The main objective of the study is to identify how students utilize ChatGPT for academic purposes. Specifically, the study aims to verify the various activities for which students employ ChatGPT, analyze their motivations for using the tool, and assess their attitudes towards ChatGPT technology. This includes evaluating their trust, sense of security, perceived reliability, and the impact of ChatGPT on their creativity and critical thinking skills. Additionally, the study seeks to examine the educational needs of students regarding the effective use of ChatGPT in a university setting.

To obtain the results, a survey method was applied using the CAWI (Computer-Assisted Web Interview) technique. The study was conducted in April and May 2024 among students of the Faculty of Management at the University of Gdańsk. The sample consisted of 260 respondents, exclusively full-time students (both undergraduate and graduate). In this study, the selective quota sampling procedure was employed. The characteristics of the respondents are presented in Table 2.

Table 2.
The respondents' demographic data by gender and age

Gender										
	Female			Male			Other			Total
no.	174			81			5			260
%	66.9			31.2			1.9			100
Age										
	17	18	19	20	21	22	23	24	25+	Total
no.	1	13	31	54	51	51	32	17	10	260
%	0.4	5	11.9	20.8	19.6	19.6	12.3	6.5	3.9	100

Source: own elaboration.

In the following sections, there are presented research findings that provide insights into how students of the management faculty use ChatGPT and their attitudes toward it across different factors. The analysis focuses on students from the Management Faculty at the University of Gdańsk, studying programs such as management, finance, accounting, information technology and econometrics. These programs were chosen due to their emphasis on tasks related to managing large datasets, which are valuable in business management, finance, marketing and data management in IT or using programming and querying languages. These fields prepare graduates for careers in various business domains and are intrinsically linked with data operation, content creation, and service design.

4. Results

The initial phase of the study focused on verifying whether respondents are using ChatGPT for academic purposes. The findings reveal that an overwhelming majority of respondents (93.8%) utilize ChatGPT in their academic activities, while only 6.2% reported not using the tool.

Thus, the sample for further analysis included only those who use ChatGPT (n = 244). At the time of the study, two versions of ChatGPT were available: GPT-3.5 (free version) and GPT-4.0 (paid version). Students were asked which version of ChatGPT they were using, with an additional option to indicate if they were unsure. The results are as follows: 86.9% use the free version, 7.8% use the paid version, and 5.3% are unsure which version they use (presumably the free version).

It is important to note that ChatGPT is evolving dynamically. At the time the study was conducted, GPT-3.5 was available, but during the analysis of the results, this version was no longer accessible. It is highly likely that future development will bring additional versions with enhanced functionalities. The question regarding the version used aimed to verify whether students opt for a paid subscription, as this may influence their usage patterns. However, the names and features of ChatGPT versions may vary in the future, which is a factor worth considering in subsequent studies.

The frequency of ChatGPT usage for academic purposes was also examined among the students who use the tool. The results are as follows: 4.9% use it daily, 38.9% several times a week, 32% several times a month, 13.5% once a week, and 10.7% less than once a month. This indicates that the vast majority of students use AI support several times a month or several times a week. In the next part, the study examined for which tasks students employ ChatGPT and what their motivations are for using the tool. The results are presented in Table 3.

Table 3.
The structure of the respondents' answers regarding the usage of ChatGPT and motivations for academic tasks

Items	**Yes**		**No**		**Total**	
	answers					
	no.	%	no.	%	no.	%
Activities						
quick information retrieval	177	72.5	67	27.5	244	100
assistance with writing papers and assignments	167	68.4	77	31.6	244	100
support in understanding difficult concepts (easy explanations)	103	42.2	141	57.8	244	100
language correction of texts (writing in a more polished language)	79	32.4	165	67.6	244	100
help with studying (interactive Q&A sessions)	58	23.8	186	76.2	244	100
translating texts into other languages	44	18.0	200	88.0	244	100
I use ChatGPT for academic tasks because…						
I want to minimize the time needed to complete the task	157	64.3	87	35.7	244	100
I want to minimize the effort required for the task	92	37.7	152	62.3	244	100
I want to do the task correctly (avoid mistakes)	124	50.8	120	49.2	244	100
I seek inspiration or refine my ideas to make the task even better	190	77.9	54	22.1	244	100

Source: own elaboration.

The results indicate that the most common use of ChatGPT among students is for quick information retrieval, with 72.5% of respondents using it for this purpose. Assistance with writing papers and assignments follows closely at 68.4%. However, fewer students use ChatGPT for understanding difficult concepts (42.2%), language correction (32.4%), interactive Q&A sessions (23.8%), and translating texts (18.0%).

Regarding motivations, the primary reasons for using ChatGPT are seeking inspiration or refining ideas (77.9%) and minimizing the time needed to complete tasks (64.3%). Half of the students use it to ensure tasks are done correctly (50.8%), while a smaller proportion aims to minimize effort (37.7%). These findings suggest that while ChatGPT is widely used for efficient information retrieval and enhancing the quality of academic tasks, students are also motivated by the desire to save time and improve their work quality.

In the final part of the study, the focus was on assessing students' attitudes towards ChatGPT. This involved constructs such as evaluating their level of trust, sense of security, perceived reliability, and the impact of ChatGPT on their creativity and critical thinking skills. Each construct was measured using one or two items. Additionally, the study aimed to identify the educational needs of students for the effective use of ChatGPT within the university setting.

A five-point Likert scale was used to assess attitudes. Respondents were asked to indicate their level of agreement with statements about using ChatGPT. The results are presented in Table 4.

Most respondents agree that they trust the information obtained from ChatGPT. Over one-third (38.5%) agree or strongly agree with this statement, while 29.1% somewhat disagree or strongly disagree. A neutral stance was expressed by 32.4% of respondents. These results suggest that although there is a certain level of trust, a significant portion of students remain skeptical or neutral. On the other hand, the majority of respondents (44.2%) strongly agree that they verify information obtained from ChatGPT using other sources, and 36.1% agree with this statement. Only 11.5% of respondents do not feel the need to verify information. This indicates a cautious approach by students towards information obtained from ChatGPT and frequent verification of this information through other sources.

Respondents' opinions on privacy and data protection are divided. About 40.2% agree (or strongly agree) that they have no privacy concerns. On the other hand, a similar portion, 37.3%, somewhat disagree (or strongly disagree) with this statement. A neutral stance was expressed by 22.5% of respondents. These results indicate some concerns about privacy and data protection among a portion of the respondents.

Opinions on the reliability of ChatGPT are diverse. Approximately 34.8% of respondents agree that ChatGPT always answers their questions, with an additional 5.7% strongly agreeing with this statement. However, 29.5% somewhat disagree, and 15.2% strongly disagree, indicating significant reservations about its reliability. A neutral stance was expressed by 14.8% of respondents. These results suggest that while many users consider ChatGPT to be reliable, there is a substantial group that harbors doubts.

Most respondents believe that ChatGPT provides new ideas and perspectives. About 47.5% agree, and 24.2% strongly agree with this statement (a combined total of 71.7%). Only 3.7% strongly disagree, and 11.5% somewhat disagree. A neutral stance was expressed by 13.1% of respondents. These results suggest that students perceive ChatGPT as a valuable source of inspiration. On the other hand, 30.3% agree that excessive use of ChatGPT may negatively affect their creativity, and 27.1% strongly agree with this statement (a combined total of 57.4%). About 17.2% somewhat disagree, and 9.4% strongly disagree, indicating some concerns about its impact on creativity. A neutral stance was expressed by 16.0% of respondents. This indicates that despite recognizing ChatGPT as a source of inspiration, there is an awareness and concern about its potential impact on creativity.

Table 4.
Attitudes and perceptions of ChatGPT among students using it for educational purposes

Items	Scale	no. of answers					
		% of respondents' answers					
		aggregated amount of respondents' answers (%)					
		1 - strongly disagree	2 - disagree	3 - neither agree nor disagree	4 - agree	5 - strongly agree	total
Trust							
I trust the information I receive from ChatGPT.	no.	13	58	79	89	5	244
	%	5.3	23.8	32.4	36.5	2.0	100
	%	29.1		32.4	38.5		100
I verify the information obtained from ChatGPT with other sources.	no.	7	21	20	88	108	244
	%	2.9	8.6	8.2	36.1	44.2	100
	%	11.5		8.2	80.3		100
Security							
I have no concerns about privacy and data protection when using ChatGPT.	no.	40	51	55	70	28	244
	%	16.4	20.9	22.5	28.7	11.5	100
	%	37.3		22.5	40.2		100
Reliability							
ChatGPT always answers my questions.	no.	37	72	36	85	14	244
	%	15.2	29.5	14.8	34.8	5.7	100
	%	44.7		14.8	40.5		100
Creativity							
ChatGPT provides me with new ideas and perspectives.	no.	9	28	32	116	59	244
	%	3.7	11.5	13.1	47.5	24.2	100
	%	15.2		13.1	71.7		100
I am concerned that excessive use of ChatGPT may negatively affect my creativity.	no.	23	42	39	74	66	244
	%	9.4	17.2	16.0	30.3	27.1	100
	%	26.6		16.0	57.4		100
Critical thinking							
I am concerned that excessive use of ChatGPT may negatively affect my critical thinking skills.	no.	30	37	39	76	62	244
	%	12.3	15.2	16.0	31.1	25.4	100
	%	27.5		16.0	56.5		100
Education need							
I believe that universities should teach proper usage of ChatGPT.	no.	10	16	49	75	94	244
	%	4.1	6.6	20.1	30.7	38.5	100
	%	10.7		20.1	69.2		100

Source: own elaboration.

Similar to the concerns about creativity, 31.1% of respondents agree that excessive use of ChatGPT may negatively impact their critical thinking skills, with 25.4% strongly agreeing (a combined total of 56.5%). About 15.2% somewhat disagree, and 12.3% strongly disagree. A neutral stance was expressed by 16.0% of respondents. These results also indicate concerns about the potential impact on critical thinking skills. This suggests that users are aware of the potential negative effects of over-reliance on the AI tool.

More than two-thirds of respondents believe that universities should teach the proper use of ChatGPT. Among them, 38.5% strongly agree with this statement, and 30.7% agree. Only 4.1% strongly disagree, and 6.6% somewhat disagree. A neutral stance was expressed by 20.1% of respondents. These results indicate strong support for education in the field of AI.

Summarizing the previous results, the average for all areas was also calculated. If a construct included two items, their average was calculated. For the reverse statements (opposite of the studied feature), the scale was inverted for calculations. The results of these calculations are presented in Figure 1, providing a more precise understanding of respondents' attitudes and opinions towards ChatGPT, allowing for better insights into both the positive and negative aspects of using this tool in education.

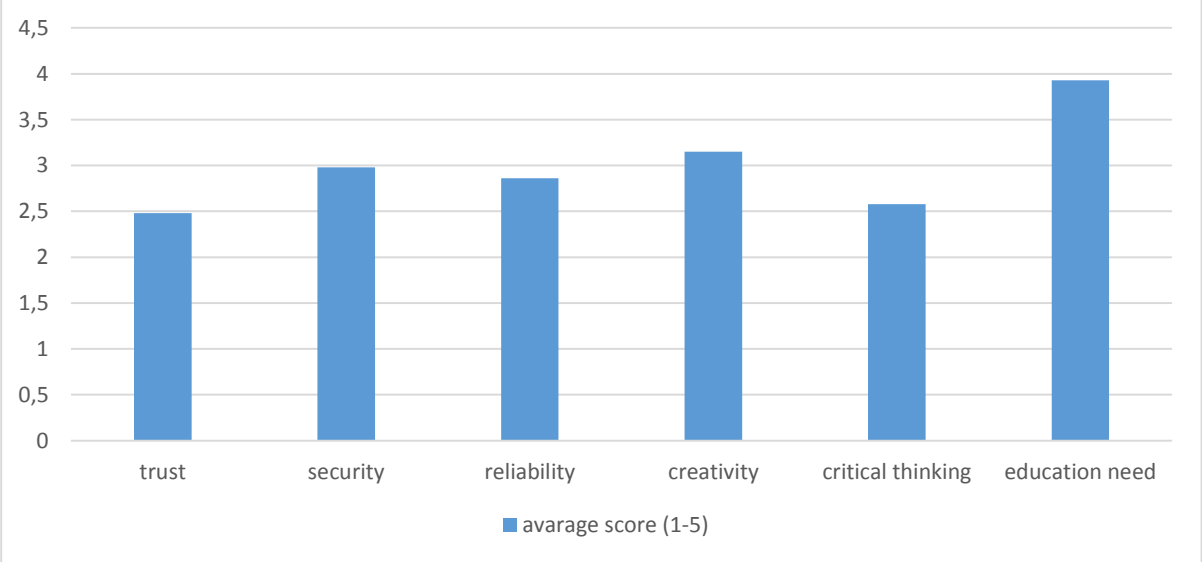

Figure 1. Mean scores of respondents' attitudes and perceptions toward ChatGPT.
Source: own elaboration.

In the graph, the X-axis represents the evaluation categories, while the Y-axis shows the mean score on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). An analysis of the mean scores for individual constructs shows diverse student attitudes towards ChatGPT. The highest mean was for the construct regarding the need for education (3.93), indicating a strong belief among students that universities should teach the proper use of ChatGPT. Creativity scored a mean of 3.15, suggesting that students see ChatGPT as a valuable source of inspiration and new ideas. On the other hand, trust (2.48), security (2.98), reliability (2.86), and critical thinking (2.58) scored lower. These results indicate some concerns among students about these aspects. The lowest mean was for the trust construct, suggesting that students are not fully convinced of the reliability of the information obtained from ChatGPT.

5. Discussion

The findings of this study align with the growing body of research highlighting the transformative potential of ChatGPT in higher education. Consistent with previous studies, the results indicate that ChatGPT is widely used by students for various academic tasks, including quick information retrieval, writing assistance, and idea generation. The high adoption rate of ChatGPT observed in this study (93.8% of respondents) mirrors findings by Farhi et al. (2023) and Singh et al. (2023), who documented similar enthusiasm for generative AI tools among students.

One significant contribution of this study is the detailed analysis of student motivations for using ChatGPT. Most respondents cited time efficiency and task quality improvement as primary drivers, reflecting trends identified by Rehman et al. (2024), who noted that ChatGPT enhances productivity and satisfaction. This focus on efficiency aligns with the observed preference for features such as quick information retrieval and personalized assistance.

These findings can be interpreted through the lens of the Technology Acceptance Model (TAM), which emphasizes perceived usefulness and perceived ease of use as critical determinants of user acceptance. The high percentage of students who use ChatGPT to minimize task time (64.3%) or improve outcomes (50.8%) reflects strong perceived usefulness. Similarly, widespread use for idea generation (77.9%) suggests that students find the tool easy and intuitive to use, reinforcing TAM's second key construct - perceived ease of use.

However, the study also highlights several challenges associated with ChatGPT's use in education. Concerns about trust, reliability, and its potential impact on critical thinking and creativity were evident among respondents. These findings are consistent with previous literature (Rehman et al., 2024; Sundkvist & Kulset, 2024), which emphasized that while ChatGPT offers significant advantages, its limitations—such as biased responses and over-reliance—pose challenges for educational integrity and student development. Notably, over half of the respondents in this study expressed concerns about ChatGPT's effect on creativity and critical thinking, corroborating the cautionary insights of Mennella (2024).

The dynamic nature of ChatGPT adoption necessitates further research, especially given potential differences across countries, types of institutions (technical, artistic, medical), fields of study, as well as demographic factors such as gender and age. Cultural nuances and institutional contexts may significantly influence how students and educators perceive and utilize AI tools, as supported by Elbaz et al. (2024) and Acosta-Enriquez et al. (2024). Addressing these dimensions can help in tailoring effective educational strategies.

The findings also underline the importance of structured educational initiatives. A strong majority of respondents advocated for universities to teach the proper use of ChatGPT, highlighting the need for structured guidelines and educational interventions. This aligns with the recommendations of Almogren et al. (2024), who emphasized the role of comprehensive

training programs in ensuring the responsible use of generative AI in education. Additionally, equipping university staff with the necessary digital skills to stay ahead of technological trends—particularly given the proficiency of Generation Z in navigating these tools—is a pressing challenge that requires institutional attention.

Furthermore, the study points to both benefits and risks associated with ChatGPT in education. Benefits include individualized learning, self-checking, and accelerated processes, while risks involve cybersecurity threats, data privacy concerns, and intellectual property issues. Questions about the long-term implications of using such tools, including their potential to undermine creativity and critical thinking, remain open. These findings echo the need for balanced integration of ChatGPT, as its short period of availability limits comprehensive evaluation of its long-term impact.

6. Conclusion

This study contributes to the understanding of ChatGPT's role in higher education, providing insights into student usage patterns, motivations, and perceptions. The high adoption rate of ChatGPT demonstrates its utility as a versatile tool for academic purposes, offering benefits such as enhanced productivity, improved learning outcomes, and personalized support. However, challenges related to trust, reliability, and the potential impact on creativity and critical thinking highlight the need for a balanced approach to integrating generative AI in education.

The findings also underscore the significant need for education on the ethical and effective use of AI tools. To address this, educational institutions should take proactive steps to equip students with the necessary skills and knowledge for responsible AI use. These measures could include organizing workshops on the ethical application of ChatGPT and other generative AI technologies, as well as implementing policies to regulate their use in academic assessments, such as exams. By acknowledging both the potential and limitations of these technologies, universities can foster a balanced and conscious approach to integrating AI into education. To put these recommendations into practice, institutions could introduce pilot projects where ChatGPT is used under supervision in selected courses, offer training for educators on how to use AI responsibly in teaching, and review assessment formats to better support originality and critical thinking. These steps may help ensure that AI is used in a way that supports learning while protecting academic values.

Concrete risks have already appeared in academic contexts, including the use of ChatGPT to generate entire essays without proper attribution, which raises concerns about plagiarism. Another issue is the spread of false or misleading information caused by AI hallucinations - situations where the model produces content that sounds convincing but is factually incorrect

or entirely fabricated. These challenges show how important it is to teach students to think critically about AI-generated content and understand when it supports learning and when it replaces their own work.

Addressing these challenges requires a multi-faceted strategy. Universities should focus on developing clear institutional guidelines and good practices, as well as offering training programs for faculty members to help them effectively incorporate AI into teaching and stay ahead of technological advancements. Furthermore, the potential for ChatGPT to reshape traditional assessment methods—such as essay writing or case study analyses—underscores the need for innovation in academic evaluation.

Future efforts should also explore the dynamic and context-specific aspects of ChatGPT adoption, considering differences across cultures, institutions, and disciplines. Additionally, longitudinal studies are needed to assess whether the benefits of ChatGPT outweigh its risks in the long term. By fostering informed and responsible use of ChatGPT, educational institutions can harness its potential to support meaningful learning experiences while mitigating its risks.

References

1. Acosta-Enriquez, B.G., Arbulú Pérez Vargas, C.G., Huamaní Jordan, O., Arbulú Ballesteros, M.A., Paredes Morales, A.E. (2024). Exploring attitudes toward ChatGPT among college students: An empirical analysis of cognitive, affective, and behavioral components using path analysis. *Computers and Education: Artificial Intelligence*, *7*, 100320. https://doi.org/10.1016/j.caeai.2024.100320
2. Al Muid, M.A., Reza, M.M., Kalim, R.B., Ahmed, N., Habib, M.T., Rahman, M.S. (2021). EduBot: An unsupervised domain-specific chatbot for educational institutions. In: T. Masrour, I. El Hassani, A. Cherrafi (Eds.), *Lecture Notes in Networks and Systems. Artificial Intelligence and Industrial Applications* (pp. 166-174). Cham: Springer International Publishing.
3. Almogren, A.S., Al-Rahmi, W.M., Dahri, N.A. (2024). Exploring factors influencing the acceptance of ChatGPT in Higher Education: A Smart Education Perspective. *Heliyon*, *10(11),* e31887. https://doi.org/10.1016/j.heliyon.2024.e31887
4. Atlas, S. (2023). *ChatGPT for Higher Education and Professional Development: A Guide to Conversational AI.* https://digitalcommons.uri.edu/cba_facpubs/548
5. Berente, N., Gu, B., Recker, J., Santhanam, R. (2021). Managing Artificial Intelligence. *MIS Quarterly*, *45(3),* 811-836. https://doi.org/10.25300/MISQ/2021/16274
6. Brynjolfsson, E., Mitchell, T. (2017). What Can Machine Learning Do? Workforce Implications. *Science*, *358(6370),* 1530-1534. https://doi.org/10.1126/science.aap8062

7. Caldarini, G., Jaf, S., McGarry, K. (2022). A Literature Survey of Recent Advances in Chatbots. *Information*, *13(1),* 41. https://doi.org/10.3390/info13010041
8. Castelvecchi, D. (2016). Can We Open the Black Box of AI? *Nature*, *538(7623),* 20-23. https://doi.org/10.1038/538020a
9. Chellappa, V., Luximon, Y. (2024). Understanding the perception of design students towards ChatGPT. *Computers and Education: Artificial Intelligence, 7*, 100281. https://doi.org/10.1016/j.caeai.2024.100281
10. Cotton, D.R.E., Cotton, P.A., Shipway, J.R. (2024). Chatting and cheating: Ensuring academic integrity in the era of ChatGPT. *Innovations in Education and Teaching International, 61(2),* 228-239. https://doi.org/10.1080/14703297.2023.2190148
11. Davis, F.D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13(3),* 319-340. https://doi.org/10.2307/249008
12. Dwivedi, Y., Kshetri, N., Hughes, L., Slade, E., Jeyaraj, A., Kar, A. et al. (2023). So what if ChatGPT wrote it? *Multidisciplinary perspectives on opportunities, challenges and implications of generative conversational AI for research, practice, and policy, 71(1-18).*
13. Elbaz, A.M., Salem, I.E., Darwish, A., Alkathiri, N.A., Mathew, V., Al-Kaaf, H.A. (2024). Getting to know ChatGPT: How business students feel, what they think about personal morality, and how their academic outcomes affect Oman's higher education. *Computers and Education: Artificial Intelligence*, *7*, 100324. https://doi.org/10.1016/j.caeai. 2024.100324
14. Engström, A., Pittino, D., Mohlin, A., Johansson, A., Edh Mirzaei, N. (2024). Artificial intelligence and work transformations: Integrating sensemaking and workplace learning perspectives. *Information Technology & People*. Advance online publication. https://doi.org/10.1108/ITP-01-2023-0048
15. Farhi, F., Jeljeli, R., Aburezeq, I., Dweikat, F.F., Al-shami, S.A., Slamene, R. (2023). Analyzing the students' views, concerns, and perceived ethics about ChatGPT usage. *Computers and Education: Artificial Intelligence*, *5*, 100180. https://doi.org/10.1016/ j.caeai.2023.100180
16. Feuerriegel, S., Hartmann, J., Janiesch, C. et al. (2024). Generative AI. *Business & Information Systems Engineering*, *66(1),* 111-126. https://doi.org/10.1007/s12599-023-00834-7
17. Gams, M., Gu, Y.-H., Akic, H., Andrés, M., Vincent, T. (2019). Artificial Intelligence and Ambient Intelligence. *Artificial Intelligence*, *1(1),* 71-86. https://doi.org/10.3233/AIS-180508
18. Gimpel, H., Hall, K., Decker, S. et al. (2023). Unlocking the Power of Generative AI Models and Systems such as GPT-4 and ChatGPT for Higher Education. *Hohenheim Discussion Papers in Business, Economics and Social Sciences, 2*.

19. Jackson, M.O., Qiaozhu, M., Walter, Y., Yutong, X. (2024). A Turing test of whether AI chatbots are behaviorally similar to humans. *The Proceedings of the National Academy of Sciences*, *121(9)*. https://doi.org/10.1073/pnas.2313925121
20. Jalon, J.B., Chua, G.A., Torres, M.L. (2024). ChatGPT as a learning assistant: Its impact on students' learning and experiences. *International Journal of Education in Mathematics, Science, and Technology (IJEMST)*, *12(6),* 1603-1619. https://doi.org/10.46328/ijemst.4471
21. Jiang, Y., Li, X., Luo, H. et al. (2022). Quo Vadis Artificial Intelligence? *Discovery Artificial Intelligence*, *2(4)*. https://doi.org/10.1007/s44163-022-00022-8
22. Kasneci, E., Seßler, K., Küchemann, S., Bannert, M., Dementieva, D., Fischer, F. et al. (2023). ChatGPT for good? On opportunities and challenges of large language models for education. *Learning and Individual Differences*, *103*, 102274.
23. McCarthy, J. (2007). *What is Artificial Intelligence?* Stanford University.
24. McTear, M., Callejas, Z., Griol, D. (2016). *The Conversational Interface: Talking to Smart Devices.* Cham: Springer International Publishing.
25. Mennella, T. (2024). Student usage and perceptions of ChatGPT: The good, the bad, and the ugly. *Biophysical Journal*, *123(3),* 334a. https://doi.org/10.1016/j.bpj.2023.11.2035
26. Ngo, T.T.A. (2023). The perception by university students of the use of ChatGPT in education. *International Journal of Emerging Technologies in Learning, 18*(17), 4-19. https://doi.org/10.3991/ijet.v18i17.39019
27. Rehman, A.U., Behera, R.K., Islam, M.S., Abbasi, F.A., Imtiaz, A. (2024). Assessing the usage of ChatGPT on life satisfaction among higher education students: The moderating role of subjective health. *Technology in Society*, 102655. https://doi.org/10.1016/j.techsoc.2024.102655
28. Rejeb, A., Rejeb, K., Appolloni, A., Treiblmaier, H., Iranmanesh, M. (2024). Exploring the impact of ChatGPT on education: A web mining and machine learning approach. International *Journal of Management Education*, *22(1),* 100932. https://doi.org/10.1016/j.ijme.2024.100932
29. Sheikh, H., Prins, C., Schrijvers, E. (2023). *Artificial Intelligence: Definition and Background. In Mission AI. Research for Policy*. Cham: Springer. https://doi.org/10.1007/978-3-031-21448-6_2
30. Shloul, T.A., Mazhar, T., Abbas, Q., Iqbal, M., Ghadi, Y.Y., Shahzad, T., Malik, F., Hamam, H. (2024). Role of activity-based learning and ChatGPT on students' performance in education. *Computers and Education: Artificial Intelligence*, *6*, 100219. https://doi.org/10.1016/j.caeai.2024.100219
31. Singh, H., Tayarani-Najaran, M.-H., Yaqoob, M. (2023). Exploring computer science students' perception of ChatGPT in higher education: A descriptive and correlation study. *Education Sciences, 13*(9), 924. https://doi.org/10.3390/educsci13090924

32. Sundkvist, C.H., Kulset, E.M. (2024). Teaching accounting in the era of ChatGPT – The student perspective. *Journal of Accounting Education*, *69*, 100932. https://doi.org/10.1016/j.jaccedu.2024.100932
33. Turing, A. (1950). Computing Machinery and Intelligence. *Mind*, *59(236),* 433-460.
34. Youssef, E., Medhat, M., Abdellatif, S., Al Malek, M. (2024). Examining the effect of ChatGPT usage on students' academic learning and achievement: A survey-based study in Ajman, UAE. *Computers and Education: Artificial Intelligence*, *7*, 100316. https://doi.org/10.1016/j.caeai.2024.100316

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ATTITUDES, INVOLVEMENT, AND EXPECTATIONS OF ACADEMIC STAFF TOWARDS THE PROCESS OF UNIVERSITY INTERNATIONALIZATION

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Purpose: Internationalization can be a process of improving a university's operations in educational, scientific, and organizational dimensions. It enhances university's attractiveness offering opportunities for staff mobility and career development on an international level. The aim of this article is to assess attitudes, behaviors, and needs of academic teachers regarding internationalization and to provide recommendations for university authorities on actions that support international exchange.
Design/methodology/approach: Research was conducted using diagnostic survey method carried out with CAWI technique and secondary research, including analysis of existing materials, literature queries, and desk research.
Findings: Research results showed that academic teachers assess level of internationalization as low or average, particularly in the area of education. Positive evaluations accounted for 16% in the area of research and collaboration, and 11% in education, alongside a high percentage of negative assessments. Predominance of average ratings and lack of opinion among some respondents may indicate low effectiveness and limited visibility of university's current internationalization efforts. This leads to conclusion that internationalization targeted at academic staff requires further action.
Research limitations/implications: Research was conducted among employees of a selected higher education institution. Conducting research on a broader sample of respondents from various universities would provide more comprehensive picture of the phenomena and help identify relationships and conditions beyond those presented in the article. Similar studies could also be conducted among administrative employees, to make a complete diagnosis.
Practical implications: Research results may be source of insight for university authorities and units responsible for internationalization processes.
Social implications: Process of internationalizing universities in Poland can create opportunities for development and increase competitiveness of higher education institutions and contribute to deepening inequalities in access to professional development opportunities among academic staff. Pressure placed on research and teaching staff to be mobile, participate

in international internships and research projects, and publish in English affects their working conditions and professional identity.
Originality/value: Subject of the study is the scope of university internationalization and its impact on improving quality of education and scientific research.
Keywords: internationalization, universities, higher education institutions, scientific research, internationalization strategy.
Category of the paper: Research paper.

1. Introduction

Among European higher education institutions, the issue of internationalization gained importance in the early 1990s. Initially, this was connected to the idea of the establishment of the European Union in 1993, whose treaties introduced, among other things, close cross-border cooperation between the institutions of the member states. At first, the programs supporting internationalization processes were designed for institutions located in the member states of the European Union. Over the time, their scope and reach expanded to include organizations and institutions from candidate or associated countries.

The first program supporting internationalization processes was launched in 1990 under the name Tempus (European Commission, 1990). It was an initiative aimed at supporting cross-border cooperation between the then-member states of the European Union and the countries of Central and Eastern Europe. The goal of the program was to modernize curricula, university management, and to support internationalization. Therefore, this form of support was available to Polish universities from the moment of its launch.

Since 1998, Polish universities could participate in academic exchange under the Socrates program (European Commission, 1989) and its Erasmus component (European Commission, 1998), which was targeted at higher education institutions. This program effectively supported academic exchange processes in the form of student exchanges, academic staff mobility, the development of the European Credit Transfer System, support for the creation of new curricula in cooperation with partner institutions, organization of intensive courses, and participation in thematic networks.

The launch of these initiatives began a process among Polish universities of identifying needs related to internationalization and, over the time, also developing and implementing appropriate strategies aimed at the internationalization of education, scientific research, and administrative support activities.

Poland's accession to the European Union in 2004, which was preceded by joining the Bologna Process (Polish Government, 1999), significantly accelerated the internationalization efforts of Polish universities. Academic exchange programs enjoyed great popularity at the time. The number of Polish students and academic staff going abroad increased year by year.

The implementation of this form of internationalization allowed Polish universities to assess their own resources and led them to develop complete study programs addressed to foreign students and offered in English. An initiative supporting the promotion of Polish universities abroad and encouraging foreigners to study in Poland was the launch as the "Study in Poland" program in 2005 (Conference of Rectors…, 2005).

In 2018, the Act on Higher Education and Science (Journal of Laws 1668, 2018) was introduced which emphasized the importance of internationalization as one of the key indicators of university quality. Despite the already well-developed international cooperation activities of Polish universities, the establishment of the Polish National Agency for Academic Exchange (NAWA, 2017) and the launch of numerous programs supporting international activity significantly intensified the international presence of Polish higher education institutions.

At present Polish universities have access to many other forms of support for internationalization. These include the aforementioned Erasmus+ program, the CEEPUS program (now under NAWA, 1995), funding from the German Academic Exchange Service (DAAD, 1925), the Polish-U.S. Fulbright Commission (Fulbright Poland, 1990), and European Universities (European Commission, 2017), among others. Support for research cooperation with international centers is also an element of many programs launched by the National Science Centre (NCN, 2010) and the National Centre for Research and Development (NCBR, 2007).

Technological progress, increasing competition in the educational and scientific market, globalization, as well as international initiatives and support from organizations and institutions in this area are factors that compel higher education institutions to undertake internationalization activities. This process is multidimensional and consists of numerous initiatives, including academic mobility, study programs in foreign languages, international research and publication cooperation, joint degree programs, and the integration of an international perspective into curricula, also known as "internationalization at home".

Internationalization in itself is not a value per se, however, the direct exchange of scientific thought, knowledge, and experience supports technological progress and the implementation of innovations. Considering the complexity of the actions taken by universities, it is also important to bear in mind the many challenges arising from organizational, technical, financial, and social constraints.

The aim of this article is to assess the attitudes, behaviors, and needs of academic staff regarding internationalization, and to provide recommendations for university authorities on actions that support international exchange. The article is divided into five sections. It begins with an introduction discussing the rationale behind the development of the internationalization process in Polish higher education. The second section presents a literature review, including the findings of a desk search and an analysis of previous research on university internationalization. This is followed by a detailed description of the research methodology. The subsequent section presents the study results and discussion. The article concludes with

key findings, a discussion of the study's limitations, and recommendations for future research on the internationalization of higher education institutions.

The article presents an innovative perspective on the internationalization of universities, perceiving it as a tool for institutional development. It moves away from focusing solely on the reputational and ranking-related effects of internationalization, offering instead a functional view of the process as a mean to enhance the university's overall performance.

This approach is illustrated through research that highlights the perspective of academic staff, focusing on their attitudes, involvement, expectations and the barriers they experience. While the literature often emphasizes institutional or systemic approaches, this study examines internationalization from the individual's point of view.

Another novel element is the identification of limitations specific to the Polish context, which are rarely addressed in the literature largely dominated by analyses based on Western or global models. Additionally, the authors provide concrete recommendations for university authorities on how to support internationalization. This application-oriented approach may offer an original contribution to the development of university policies.

2. Literature Review

2.1. A Review of Research on the Internationalization of Universities

Internationalization in higher education has been the subject of discussion in numerous academic articles and studies. This issue is not new, but over the years its definition has evolved, taking on various forms and meanings. As J. Knight (2003) states, in the early 21st century, the internationalization of higher education institutions referred to transnational education, education without borders, and cross-border education. At the national, sectoral, and institutional levels, it was defined as the process of integrating an international, intercultural, or global dimension into the purpose, functions, or delivery of postsecondary education. Although the definition and importance of internationalization in higher education have changed and gained prominence over time, for the purpose of this article, the above definition is adopted as appropriate and reflective of the essence of internationalization. A year later, J. Knight (2004) emphasized that a clear understanding of the definition and motivations is crucial for effectively planning and implementing internationalization strategies.

The use of student mobility numbers as a criterion for measuring the degree of internationalization in higher education has been critically assessed by U. Brandenburg and H. de Wit (2011). The authors argue for the development of a new definition of the goals and methods of internationalization that takes into account the quality and educational value of the process. J. Knight (2015) also points to the need for updating the definition of

internationalization, explaining that such an update is necessary for a better understanding of the process's implementation in the changing global context.

H. de Wit (1999), in turn, analyzes the internationalization of universities from the perspective of shifting motivations—from academic cooperation to market competition. In his publication, he argues that internationalization is evolving toward a more strategic approach, which requires the adaptation of institutional policies. Three years later, in 2002, he conducts a historical analysis of the internationalization of higher education in the U.S. and Europe, taking into account cultural and political differences.

Similarly, S. Robson (2011), studying internationalization as a transformational agenda for higher education, highlights the need for a conscious and critical approach to the process. At the same time, S. Marginson and M. van der Wende (2007) observe that globalization significantly affects higher education and that internationalization is one of the main adaptive mechanisms for institutions.

The global dimension of internationalization is discussed by M. Tight (2021), who notes that the role of higher education institutions as initiators of globalization and internationalization should not be overlooked. He also suggests that researchers themselves must step outside their national comfort zones and think and conduct research in a more global manner.

Challenges related to the process are examined by R. Mbachi (2025), who provides a decade-long analysis of internationalization efforts at the Department of Health and Care Sciences at UiT The Arctic University of Norway. The analysis of student mobility, research collaboration, and international partnerships results in strategic recommendations aimed at improving global educational practices. The findings offer valuable insights into education, research, policy, and practice that go beyond the context of the study. The article also identifies challenges such as the COVID-19 pandemic, financial constraints, and the need for cultural competencies and adaptive strategic planning. As a result, the author proposes concrete solutions, including flexible exchange programs, the use of virtual technologies, and increased international collaboration to develop higher education in a globalized world. Meanwhile, E. Jones, B. Leask, U. Brandenburg, and H. de Wit (2021) additionally recognize the urgent need to align internationalization strategies with universities' missions of social responsibility. The authors point out that this "third mission" of higher education institutions—contributing to the social, economic, and cultural development of communities—has long been a core function of universities, alongside teaching and research. Similar conclusions are drawn by B. Leask and A. Gayardon (2021), who emphasize that much of the literature published on internationalization has primarily focused inward, on how students and institutions experience and benefit from internationalization. However, it is also important to consider the real and potential impact of these actions on local and global communities. N. Healey (2023) also highlights internationalization as a process driven by social values, not just economic ones, stressing the need to pursue social justice and sustainable development.

Internationalisation cannot have the same meaning for all involved institutions. As noted by J. Knight (2021), any study of this phenomenon must take into account the differences between countries and regions of the world, recognising that the goals, rationales, approaches, risks, and benefits vary between East and West, North and South, sending and receiving countries, developed and developing nations. At the same time, she emphasises that recognising the significance and uniqueness of the local context is crucial, suggesting that internationalisation must be adapted to local circumstances and that a "one-size-fits-all" approach is not appropriate.

The European approach to internationalisation, characterised by diversity and the need to adjust to local contexts, is described by H. de Wit and F. Hunter (2015). The authors analyse the specific features of internationalisation in the European context, taking into account the diversity of educational systems.

P.G. Altbach and J. Knight (2007) analyze the motivations behind the internationalization of higher education, such as globalization, student mobility, and the need to enhance institutional competitiveness. According to the authors, both academic and economic factors are driving forces behind internationalization.

H. de Wit (2013) notes that the phenomenon of internationalisation requires rethinking, as universities have become increasingly aware that the notion of "internationalisation" is not solely related to relations between nations but, more importantly, to the relationships between cultures and between the global and the local. He adds that the internationalisation of higher education is often perceived as an end in itself rather than as a means to an end. Therefore, internationalisation should be an element of strategies aimed at enhancing the quality of education and research, which institutions too often forget in their pursuit of quantitative goals. In the same year, J. Knight (2013) discusses the evolution of university internationalisation, highlighting both its positive and negative aspects. She considers maintaining a balance between the benefits and threats resulting from this process as essential.

Changing priorities and challenges in internationalization are observed by U. Teichler (2004), who points out that beyond student mobility, issues of quality and the impact of internationalization are becoming increasingly significant. J. Stier (2004) highlights the need to understand the different ideologies underlying internationalization, enabling a more conscious and balanced approach to the process. He identifies three main approaches: idealism, instrumentalism, and educationalism.

In 2015, S. Guri-Rosenblit analyzes five pairs of opposing trends that higher education institutions must navigate in the process of internationalization. She emphasizes the need for universities to balance national priorities with global engagement, government steering with institutional autonomy, increased diversity with harmonization policies, competition with cooperation, and intellectual property with intellectual philanthropy. J.K. Hudzik (2011) presents the concept of a comprehensive approach to internationalization that encompasses all aspects of a university's operations, stressing that the internationalization process should be an integral part of an institution's mission.

Internationalisation in the context of research is addressed by T. Shih (2024). Meanwhile, issues concerning cross-organisational and cross-cultural collaboration that enhance the potential for scientific discovery, as well as international research projects based on cooperation—often delivering insights beyond what a single team could achieve—are explored in the work of J. Dusdal and J.W. Powell (2021). An approach to internationalisation based on modern technologies was described by J. Mittelmeier, B. Rienties, A. Gunter, and P. Raghuram (2021). In their study, they introduced the concept of distance internationalisation using the University of South Africa as an example of a large-scale education provider.

Student satisfaction and their perception of the quality of education on international campuses in the UAE are explored by S. Wilkins and J. Huisman (2012). They describe both criteria as crucial to maintaining a positive image of home institutions. a balance between the benefits and threats resulting from this process as essential.

Critical perspectives on internationalising curricula across various disciplinary, institutional, and geographical contexts—and how scholars reimagine curriculum internationalisation in novel ways—are presented in the book by W. Green and C. Whitsed (2015).

Among the factors limiting the internationalisation process is insufficient academic staff engagement, as discussed by F. van den Hende and J. Riezebos (2023). Young scholars—PhD candidates—are also participants in the internationalisation process. K. Chen, Y. Ding, B. Zhao, R. Guo, and L. Ning (2025) describe the transnational academic ties maintained by domestic collaborators, which constitute a vital form of academic social capital that facilitates the integration of early-career researchers into global academic networks, ultimately boosting their research output. S. Bedenlier and O. Zawacki-Richter (2025) conducted an analysis of how changes associated with internationalisation have affected universities—particularly academic staff. They examined the impacts of internationalisation on this stakeholder group and presented 25 different effects of this process at the individual, institutional, and global levels.

The competencies of academic teachers in the context of university internationalisation are analysed by A. Zelenkova (2019). Based on a case study, she highlights the need for training teachers in intercultural competencies, especially in English-taught programmes.

Internationalisation as an institutional phenomenon of strategic significance was analysed by F. van den Hende, C. Whitsed, and R.J. Coelen (2022). Their research resulted in the development of a comprehensive framework aimed at enhancing staff engagement in implementing internationalised curricula in higher education. The perception of the internationalisation process and the engagement of academic teachers is discussed by T. Bradshaw and M. Curtis (2023), emphasising that such engagement should include involvement in institutional decision-making processes.

The awareness of academic staff regarding their role in university internationalisation, as well as their expectations toward the development of international initiatives, is discussed by F. Karaferye (2019). The author stresses the need to raise academic staff awareness about their role in the internationalisation process and the importance of providing appropriate support and training prior to international mobility.

A practical guide for researchers, research managers, faculty heads, and university administrators on evaluating cooperation and structuring discussions about how a university, department, or research group should approach international collaboration was published by T. Shih, A. Gaunt, and S. Ostlung (2020). At the same time, Universities UK (2022) released a guide outlining key themes from guidelines for the higher education sector concerning the management of security issues in international research and innovation.

Over the years, both the definition and the purpose of the internationalisation of higher education institutions have evolved. The approach to this process has undergone a transformation—from an inward organisational focus, through the development of internationalisation strategies, to a response to globalisation and societal expectations. Internationalisation has thus become a factor supporting the development of innovation, competitiveness, and, ultimately, contributing to the growth of the economy. Regardless of how institutions perceive the process of internationalisation, those involved in it recognise the benefits it brings.

2.2. University Activities in the Area of Internationalization

The Law on Higher Education and Science of 2018 (Journal of Laws of 2018, item 1669) distinguishes three areas of activity for academic staff: teaching, research, and organisational work. The scope of activity is determined based on the academic position held. A research academic is obliged to conduct research activities; a research and teaching academic is expected to carry out research and conduct teaching; whereas a teaching academic is required to deliver classes to students. Regardless of the position group, all academic staff members are obligated to participate in organisational activities for the benefit of the university and to continuously improve their professional competencies. Each of these areas of activity can also be related to tasks undertaken in the context of the university's international activities (Fig. 1).

The involvement of academic staff in processes related to internationalization is essential. This involvement can be direct, such as conducting teaching activities or scientific research, but also indirect, for example through participation in committees that develop internationalization strategies or in the role of advisors in building structures that support cooperation with foreign partners. The initiatives undertaken by Polish universities in the context of internationalization include a range of activities. These have been described, among others, by M. Popowska (2016) and by G. Marinori and S.B. Pina Cordona (2024).

Figure 1. Examples of tasks carried out in the area of university internationalization.

Source: own elaboration.

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The most frequently mentioned activities are: student mobility (statistics reported in the annual reports of the Perspektywy Foundation), doctoral student mobility, academic staff and administrative personnel mobility (e.g., Erasmus+ and CEEPUS programs), organization of international conferences (University of Warsaw, 2024), double degree programs (University of Economics and Human Sciences in Warsaw, 2023), membership in international organizations and cooperation networks such as the European University Association (EUA), organization of summer schools (WSB Academy), conducting studies in foreign languages (Koźmiński University, 2025) (Fig. 2).

Moreover organization of international staff weeks (Medical University of Gdańsk, 2019), research collaboration in international teams and consortia (Gdańsk University of Technology, 2024), organization of international workshops and training sessions (Poznań University of Economics and Business, 2025), conducting MBA programs in cooperation with foreign universities (SGH Warsaw School of Economics, 2025), organization of international academic competitions or cultural festivals (Wroclaw University of Science and Technology, 2025), organization of international mentoring programs (WSB Academy, 2025), international cooperation in doctoral education (University of Gdańsk Doctoral School, 2025), as well as numerous smaller initiatives aimed at integrating and promoting inclusiveness within the international academic community, which are initiated by individual universities in the form of courses or training sessions (University of Gdańsk, 2025). These activities are also the ones in which the academic teachers are involved (Fig. 2).

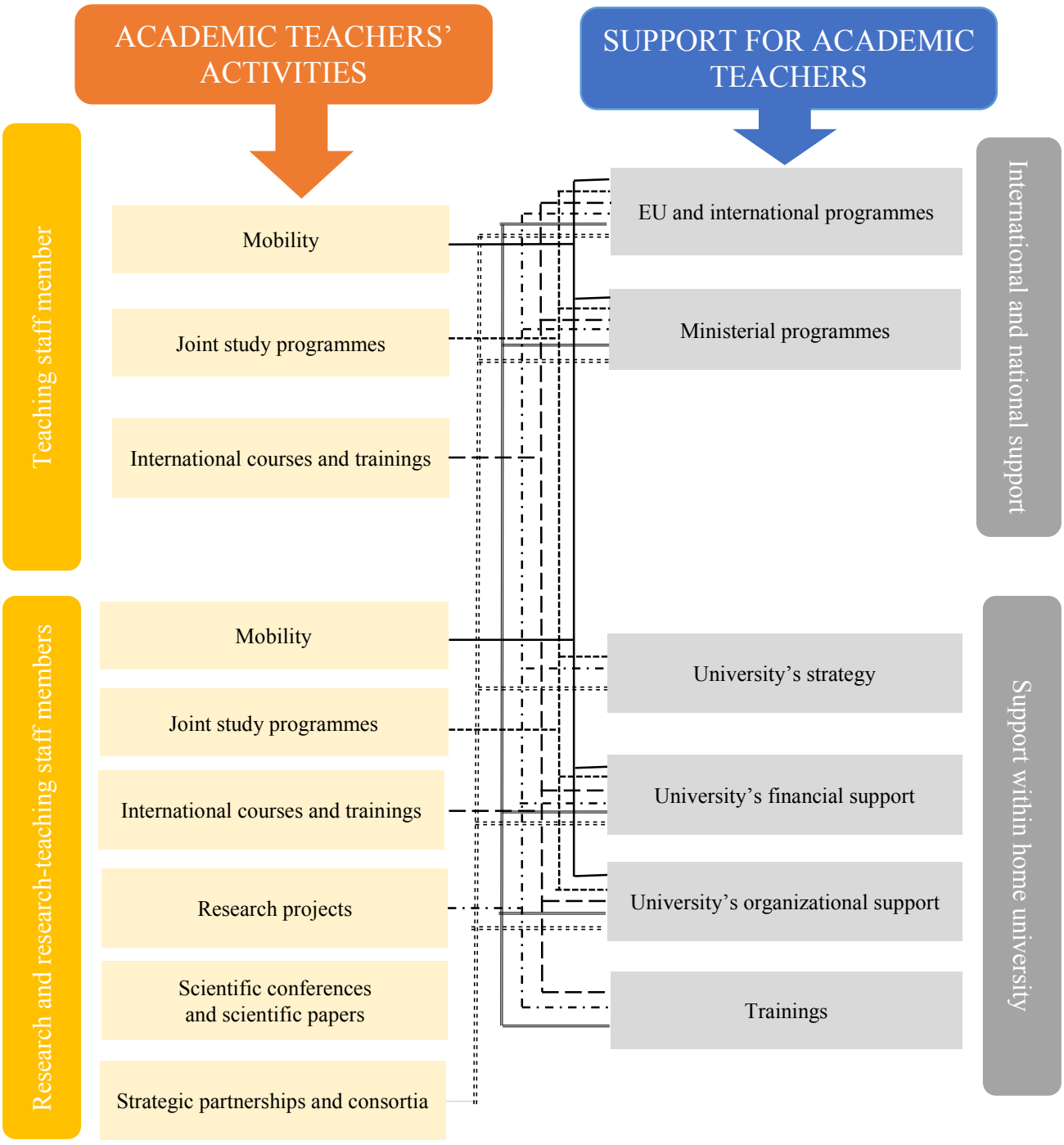

Figure 2. Academic staff activity and institutional support in the field of internationalization.
Source: own elaboration.

Polish universities also participate in programs supporting the promotion of higher education in Poland among potential international applicants within the frameworks of the Study in Poland, Study in Pomorskie, and NAWA programs.

2.3. Limitations to University Internationalization

Internationalization, like any process, can encounter various types of limitations. Among the most common organizational and technical constraints, described by authors such as A. Płoszaj (2023) and M.E. Bakay (2023), are language barriers resulting from an insufficient number of administrative staff and lecturers fluent in English, an inadequate offer of courses taught in foreign languages, insufficient institutional support for foreigners manifested in the lack or poor quality of international offices, complex administrative procedures, as well as infrastructural problems related to limited dormitory spaces and inadequate digital infrastructure supporting, for example, e-learning. The amendment to the Act on Foreigners and certain other laws introduced in May 2025 imposes additional administrative duties on universities related to servicing students and academic staff coming to Polish universities, as well as limits on the number of foreign students admitted.

The second group of limitations includes financial barriers, as mentioned by the Scientific Policy Committee of the Ministry of Education and Science (2021) and J. Mananay, J.M.P. Sanchez, H. Boholano, and M.Y. Beltran (2024). These include insufficient funding from the state budget, lack of stable financing sources such as foreign projects, higher costs of teaching in a foreign language due to the need to translate materials, double degree programs, or the necessity to hire foreign staff, which entails additional expenses. Moreover, high living costs for international students may discourage them from studying in Poland despite relatively low tuition fees.

Socio-cultural barriers, discussed by authors like J.J. Prieto-Gutierrez (2024), may relate to the low openness of academic communities to cultural diversity, lack of interest among some lecturers in teaching courses in a foreign language, or the significant workload of academic staff in research or organizational duties. On the student side, limiting factors may include integration difficulties stemming from cultural or language barriers, isolation, as well as the relatively low attractiveness of Poland as a study destination. The experiences of international students in this area have been described by E. Wąsikiewicz-Firlej, A. Szczapaniak-Kozak, and H. Lankiewicz (2022). An analysis of the internationalization of higher education in Europe identifying challenges such as cultural differences, language barriers, and tensions between economic and educational goals was conducted by S. Robson and M. Wihlborg (2019). The authors emphasize the need for a meaningful approach to internationalization that promotes intercultural dialogue and social engagement.

A comprehensive analysis of the limitations faced by Polish universities in the internationalization process was carried out by ECORYS Sp. z o.o. (2020) in a report commissioned by the National Centre for Research and Development. This report summarized the implementation of Priority Axis III of the Operational Programme Knowledge Education Development (PO WER) – Higher Education for Economy and Development.

However, as mentioned earlier, individual universities demonstrate varying levels of internationalization and may identify different factors limiting their international functioning. R.H. Neale, A. Spark, and J. Carter (2018) pointed out that regardless of the limitations, a high level of internationalization results from the commitment to key strategic priorities such as curriculum and student mobility programs, the European Union and international staff and students, cooperation with international organizations, academic and social integration of students and staff, as well as coordination of practices and processes.

The implementation of the internationalization process at universities should be subject to continuous monitoring, especially regarding limitations that pose barriers to the planned activities. Proper identification of these barriers may enable timely and appropriate steps to eliminate them. Additionally, it can serve as a starting point for reviewing the entire internationalization strategy and the resources allocated to its implementation.

3. Research Methodology

The aim of this article is to assess the attitudes, behaviors, and needs of academic teachers regarding internationalization and to provide recommendations for university authorities on actions that support international exchange. At the same time, several research questions were posed: 1) To what extent are academic teachers interested in participating in various forms of international exchange? 2) What needs do academic teachers report in the area of internationalization? 3) What limitations affect the level of internationalization? And 4) What is the level of academic teachers' engagement in internationalization activities? The research findings may serve as a valuable source of insight for university authorities and units responsible for internationalization processes.

This article employs a triangulation of research methods, including a critical literature review, the desk research method, and the diagnostic survey method. The literature review drew upon the Direct Science and Web of Science databases, resulting in the identification of 76 academic articles and reports related to the internationalization of higher education institutions. The primary research was conducted in January 2023 using a diagnostic survey administered via the CAWI (Computer-Assisted Web Interview) technique.

A questionnaire was prepared, consisting of 9 closed-ended questions that addressed, among other things: the assessment of the general level of internationalization; the current level of internationalization at the university in the areas of education and scientific activity; the evaluation of actions undertaken by the university in various functional areas to support internationalization; the identification of internationalization activities in which academic staff had participated over the past ten years or would be willing to participate in the near future; and the factors limiting their involvement in internationalization.

Some questions in the survey used a 5-point Likert scale to allow respondents to more precisely express their attitudes and opinions on the topics examined. Additionally, respondents were asked to indicate the perceived benefits of increasing the level of internationalization at their university, as well as their expectations in this regard. They were also given the opportunity to provide open-ended comments concerning the internationalization of the institution at which they are employed.

The collected data were subjected to both qualitative (descriptive) and quantitative (statistical) analysis using MS Excel and Statistica 13.0 software.

4. Results and Discussion

A total of 315 individuals were invited to participate in the study—that is, all employees holding research, research-and-teaching, or teaching positions at the examined higher education institution (Tab. 1). Ultimately, 148 respondents took part in the survey, representing 47% of the total invited. Among them, 9% held the title of professor, 22% had a postdoctoral degree (doktor habilitowany), the largest group—50%—held a PhD, and 19% held a master's or engineering degree (Tab. 2). The identity of the institution has been anonymized, as the research was not intended as a dedicated report or expert analysis, but rather focused on assessing the attitudes and engagement of academic staff toward the process of internationalization.

Table 1.
Respondent structure by academic qualifications and professional titles

Academic degree or title	Number	Percentage
Professor	13	9%
Associate professor	32	22%
Assistant professor	74	50%
Master's degree/engineer	29	19%

Source: own elaboration.

Table 2.
Respondent structure by employment group

Position	Number	Percentage
Research	13	9%
Research and teaching	113	76%
Teaching	22	15%

Source: own elaboration.

The results of the survey conducted among academic teachers showed that their highest level of activity concerns participation in international scientific conferences as a speaker presenting a paper in English, as indicated by 69% of respondents, and conducting classes in English in Poland for students (e.g., Erasmus+ program), confirmed by 45% of respondents. Academic staff activity is also evident in participation in expert activities for foreign entities (40% of all respondents), participation in the preparation of R&D offers in English (34%), and participation in the implementation of scientific and research projects (31%). Additionally, 32% of respondents indicated their internationalization activity in the area of co-authorship of scientific publications with researchers from abroad (Fig. 3).

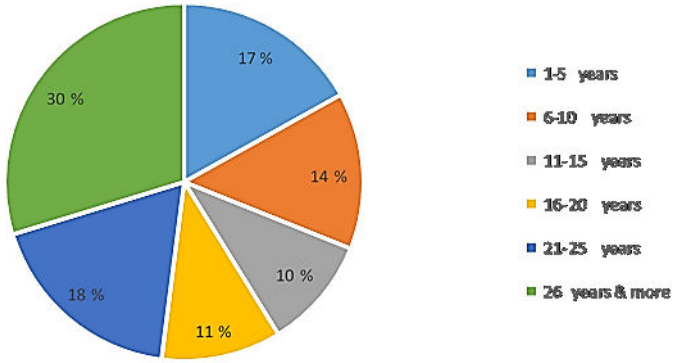

Figure 3. Respondent structure by years of professional experience.

Source: own elaboration.

Unfortunately, still relatively few academic teachers (14%) take part in the preparation of externally funded scientific or research, development, or teaching projects in partnership with external stakeholders, as well as in scientific and research internships at universities or research institutions abroad (14%). Furthermore, only 11% declared participation in Erasmus+ Staff Teaching Mobility, and just 2% reported mobility to foreign universities to conduct classes in English (outside the Erasmus+ program). Only a small percentage of academic teachers (7%) are involved in development or teaching projects financed from external sources in partnership with foreign entities. Other forms of activity, such as providing services for foreign guests visiting the university, training in multiculturalism, intercultural communication, and cultural differences, are rather incidental. Nearly 5% of respondents stated that they had not undertaken any internationalization-related activity at their place of employment (Fig. 4).

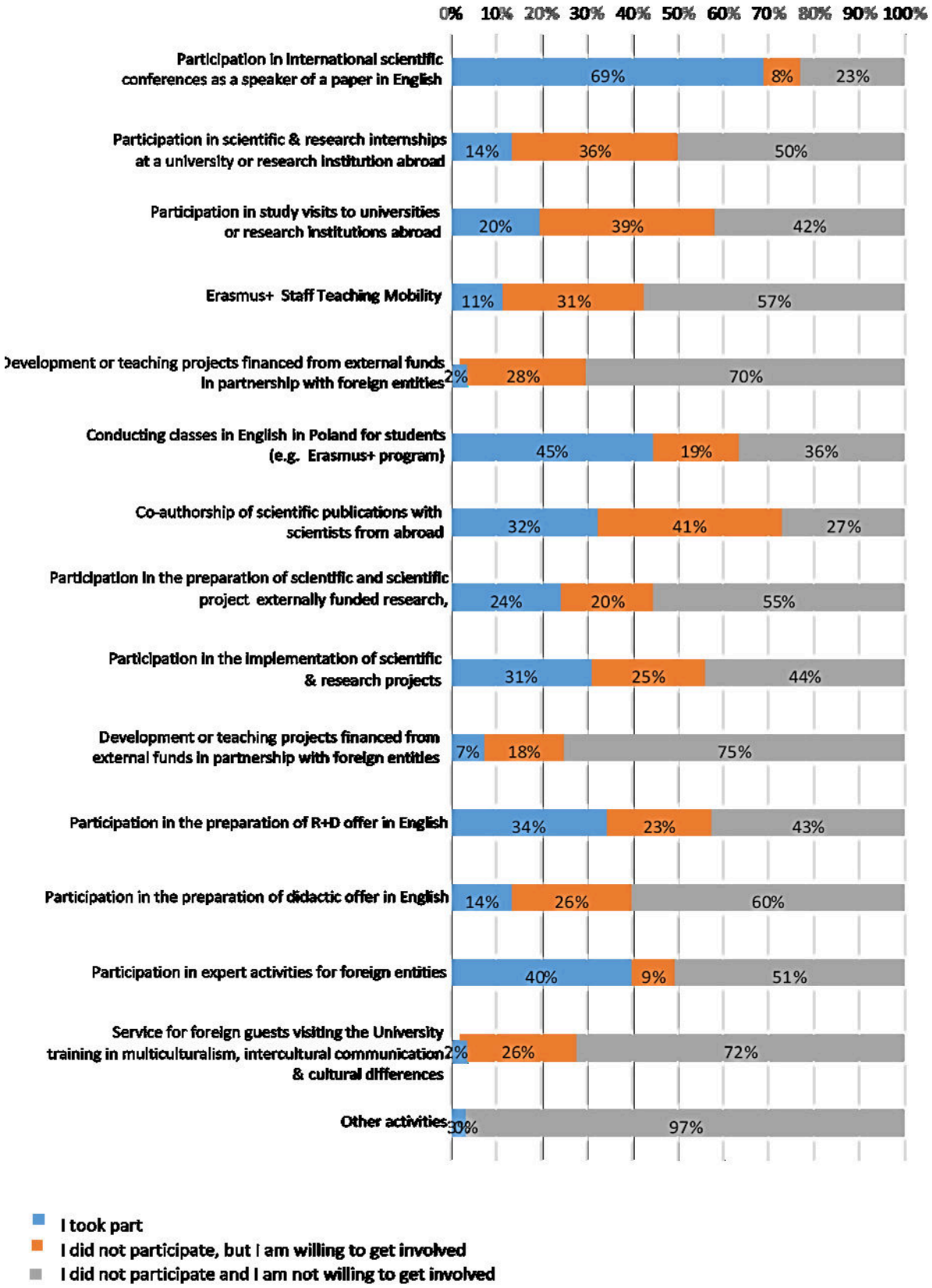

Figure 4. Internationalization activities of University in which respondents have been involved over the past 10 years.

Source: own elaboration.

Respondents were also asked about their expectations toward university authorities regarding support for internationalization efforts. The majority indicated the need for language courses for staff (71%), which confirms the existence of language barriers. A significant portion also emphasized the necessity of greater financial support for international mobility (62% of all respondents) and the introduction of a motivation system. Another important aspect identified by respondents was the need for the university to offer educational programs in English (51%) and to develop double-degree programmes (26%).

Moreover, respondents believed that the university's promotion on international markets is insufficient and that efforts in this area should be strengthened (48%), including the preparation of professional promotional materials in English (36%) (Fig. 5).

Most respondents indicated that the key to advancing internationalization is the development of an attractive educational offer in English by the university, along with the simplification of admission procedures for international students. Equally important is the provision of appropriate support for foreigners, for example through the establishment of a Welcome Center (as indicated by 37% of respondents), as well as through language and cultural support and the creation of favorable employment conditions for international staff, including streamlined administrative procedures. These measures are intended to enhance the university’s appeal to both international students and academic staff.

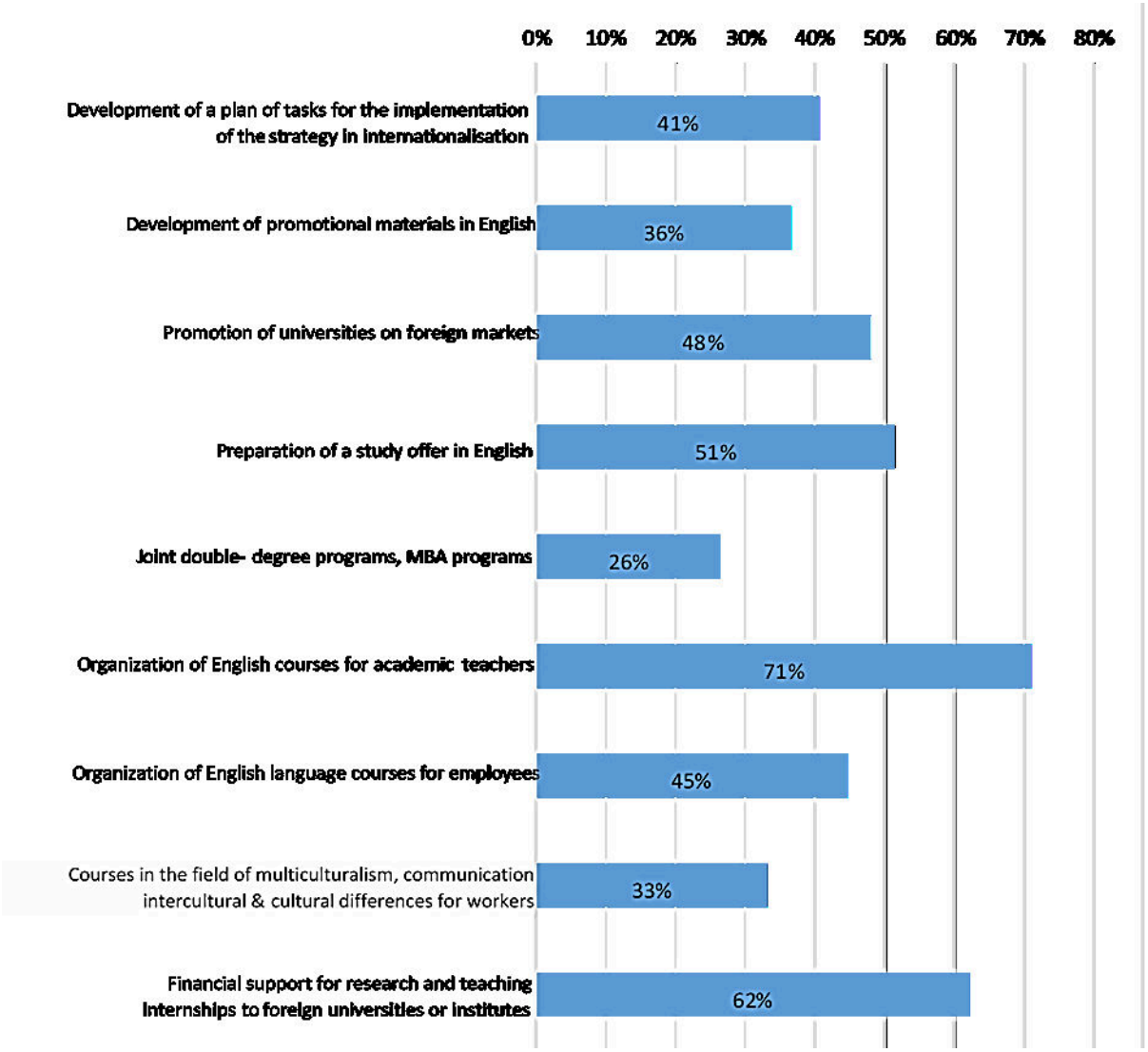

Figure 5. University actions expected by respondents in the area of internationalization – Part 1. Source: own elaboration.

Respondents also emphasized the need for project support in securing international grants (mentioned by 53% of respondents). Although various activities are being carried out at most universities under the ERASMUS+ program, respondents noted that the existing offerings fall short of actual needs (as indicated by 45% of respondents), since the demand for mobility opportunities often exceeds the number of available placements (Fig. 6).

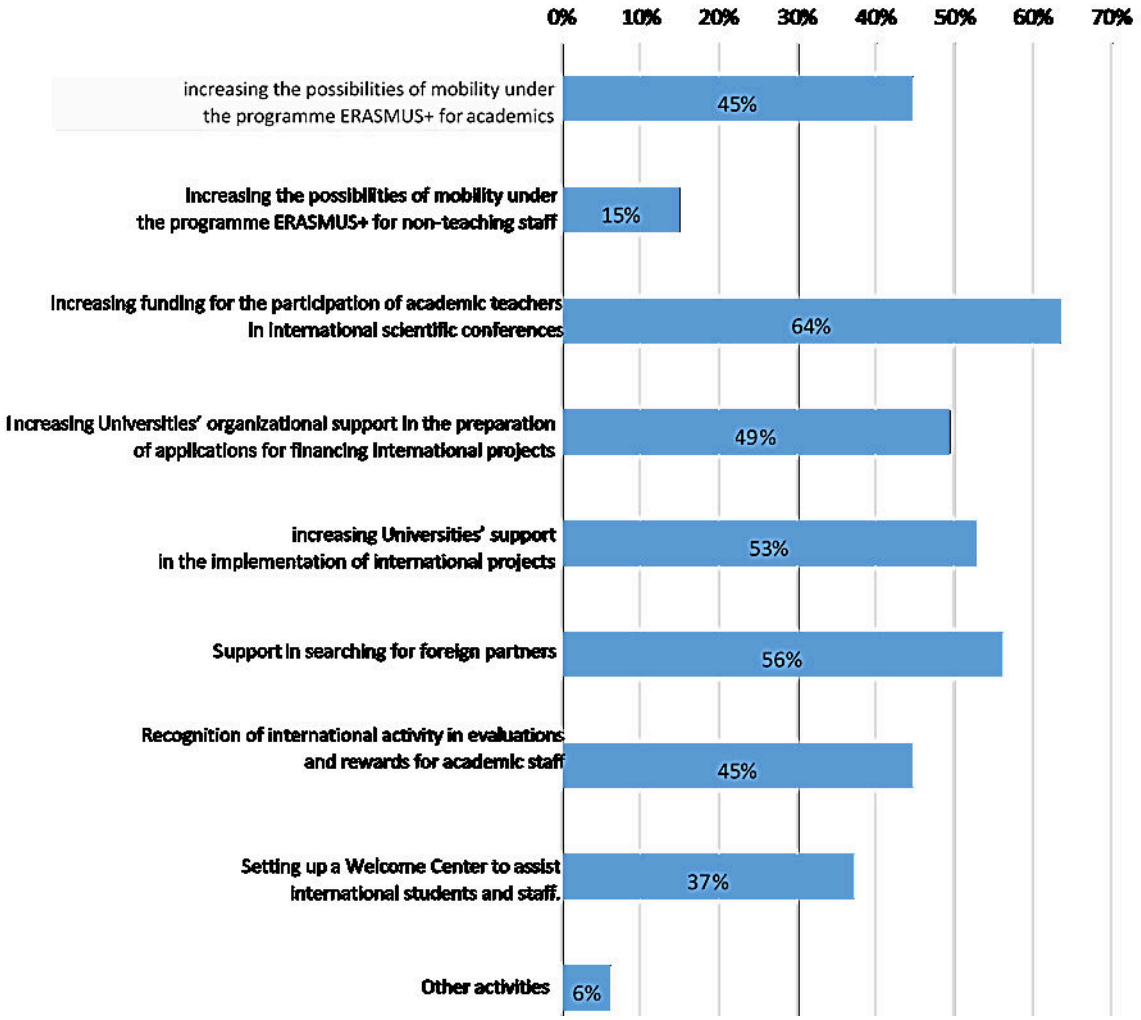

Figure 6. University actions expected by respondents in the area of internationalization – Part 2. Source: own elaboration.

Respondents were also asked to share their views on the factors that hinder or limit their involvement in the university's internationalization process. In their responses, participants emphasized the lack of a systemic approach to internationalization at the institution, which they attributed to insufficient organizational and financial support from university authorities for international activities (as noted by 64% of respondents), as well as a lack of genuine engagement from unit leadership in international efforts. According to the respondents, most initiatives are typically bottom-up, driven by individual academic staff members themselves.

The only exception identified was the ERASMUS+ program, in which the university provides administrative and financial support for teaching mobility. The situation appears less favorable when it comes to other forms of international activity, as the university reportedly lacks a structured offer for international collaboration. Respondents also highlighted the insufficient financial support for international engagement, particularly in the areas of participation in research fellowships or visiting professorships.

Furthermore, a lack of financial incentives for engaging in international activities—including teaching in English—was pointed out as a major barrier. Another serious issue identified by the respondents was the logistical burden and heavy teaching loads borne by academic staff. Internationalization is often perceived as an additional, unpaid responsibility rather than an integral part of academic work.

In addition, many staff members struggle with English proficiency, and the support offered by the university in this regard is sporadic and short-term, whereas a more systemic approach is needed. Respondents also cited administrative difficulties and excessive bureaucracy related to the process of concluding international cooperation agreements. Finally, it was noted that a significant portion of academic staff is of advanced age, which also poses a barrier to the development of internationalization due to limited mobility (Fig. 7).

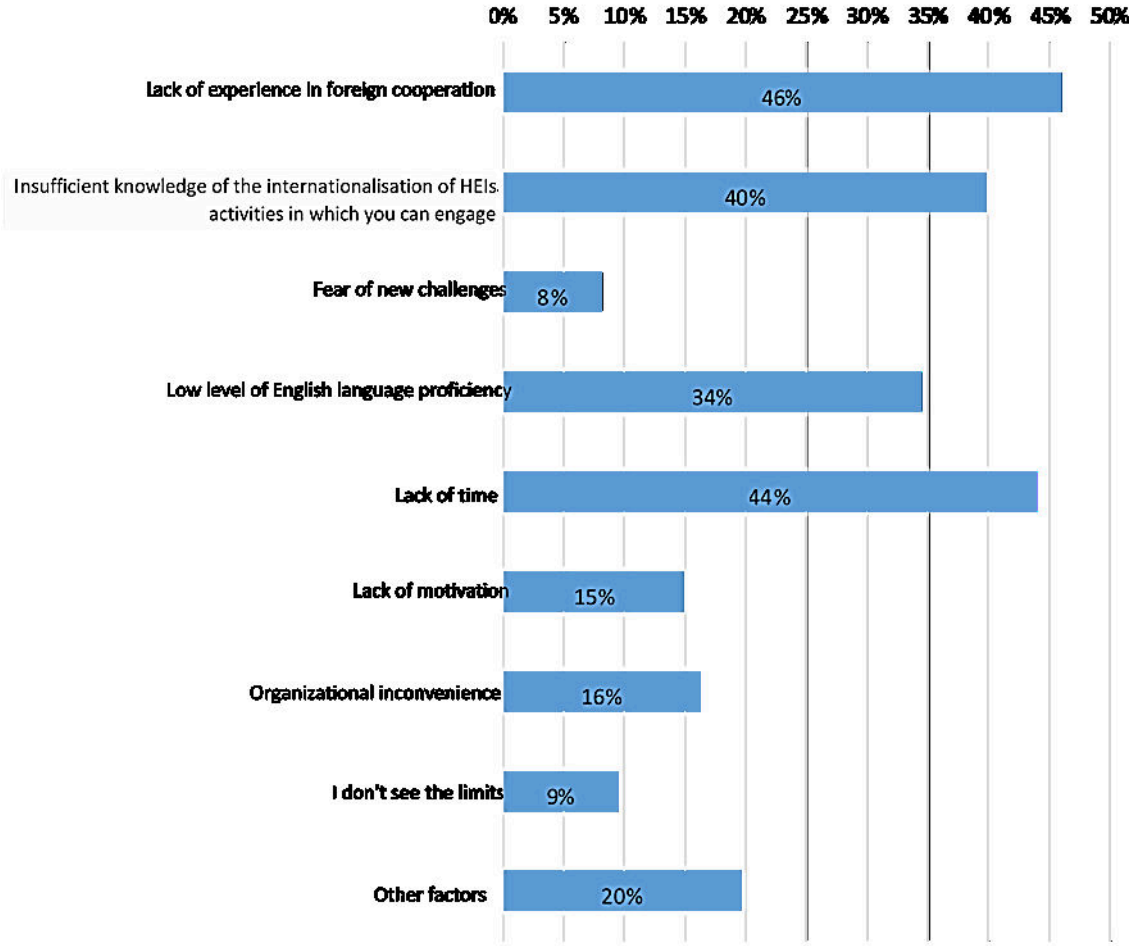

Figure 7. Factors limiting the involvement of respondents in activities related to internationalization. Source: own elaboration.

An important research question concerned the level of interest among academic staff in participating in various forms of international exchange. The study results revealed that over 50% of all respondents reported a lack of engagement and reluctance to participate in different internationalization activities. The highest levels of inactivity were observed in the areas of establishing cooperation in the development or implementation of teaching projects with

foreign entities (75%) and in participating in services for foreign guests, intercultural communication, and similar activities (72%).

Surprisingly, more than half of the respondents (57%) also expressed little interest in participating in Erasmus+ Staff Teaching Mobility, as well as in externally funded research or teaching projects (55%). Few respondents reported involvement in internships at foreign universities (50%). Slightly lower levels of reluctance were observed regarding participation in the implementation of scientific projects (44%), conducting classes in English in Poland (36%), and taking part in study visits abroad (42%). The least reluctance was shown in relation to participation in international conferences as a speaker in English—only 23% of respondents were disengaged or uninterested—as well as in co-authorship with foreign scientists (27%).

Respondents were also asked to assess the overall level of internationalization in scientific and research activities within their unit, using a five-point Likert scale. The results showed that only 16% of all respondents rated the level of internationalization as high or very high, while as many as 33% assessed it as low or very low. This may point to a general shortfall in international collaboration in research and development. Notably, a significant portion of respondents (15%) had no opinion on the matter, which may reflect either a lack of personal experience or limited awareness of such activities.

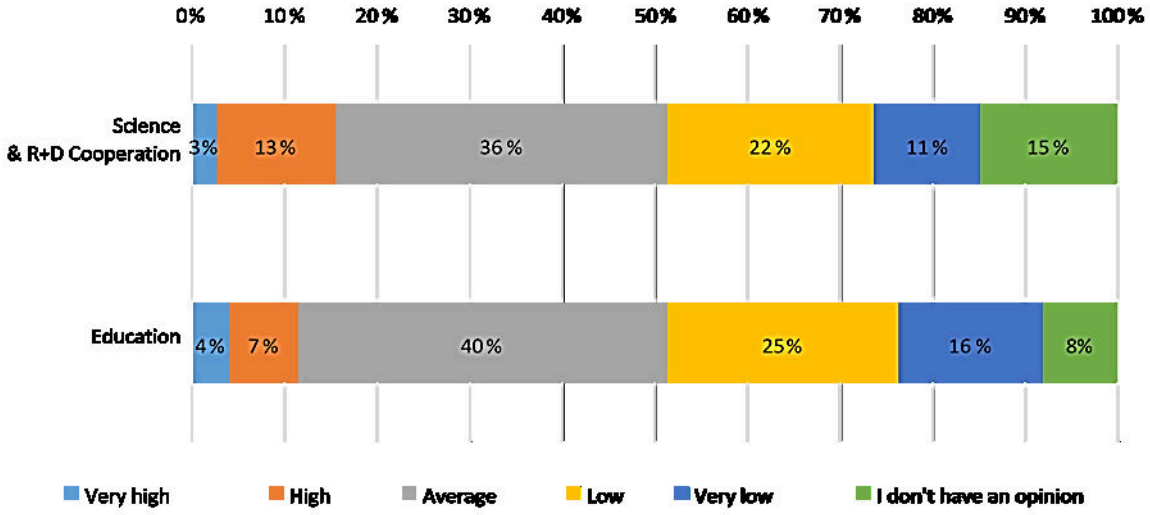

Figure 8. Assessment of the level of internationalization at the university where respondents are employed.

Source: own elaboration.

In turn, when asked to evaluate the level of internationalization in educational activities, only 11% of respondents rated it as high or very high, whereas over 41% assessed it as low or very low. This may be due to a limited number of courses offered in English, a low proportion of international students, or limited teaching mobility. A considerable share of respondents (40%) evaluated the level of educational internationalization as average (Fig. 8).

5. Conclusions

The barriers identified by the respondents also concerned the university as an organizational context. Interestingly, the persistence of old operational patterns - such as a lack of experience in international collaboration or lack of time - was among the most frequently mentioned barriers to the internationalization process, alongside the financial constraints.

Although limited proficiency in English was not cited as one of the leading barriers, it ranked first on the list of expectations, indicating a strong demand for language support. Also relatively high on the list was the insufficient knowledge among academic staff about the internationalization of higher education institutions and the types of activities they could engage in. This may reflect a lack of involvement in internationalization processes, which are crucial to the long-term development of the university, but also a perceived lack of adequate administrative support. The limited engagement of staff may, in turn, result from insufficient communication, a lack of clear explanation of the benefits and risks, as well as real obstacles - such as excessive workloads.

The study was conducted among academic teachers at only one university. Its results should not be generalized or applied to all Polish higher education institutions. Moreover, at the institution under study, faculty members participated in only a portion of the internationalization activities identified in the cited literature. Only slightly under half of the individuals targeted by the study participated in it.

At the same time, the presented results made it possible to identify areas whose strengthening and development could enable university authorities to intensify the internationalization process and engage a larger group of academic teachers in its implementation. Eliminating the described limitations would enhance the university's staff potential, which in turn could lead to improved quality of education and research, as well as increased competitiveness of the university as a place to study and conduct scientific research.

The surveyed academic teachers emphasized the average level of internationalization culture at the institutional level. They assessed the degree of internationalization in the areas of research and education as average or low, which should serve as a clear signal to university authorities that more intensive efforts in this area are necessary. University leadership should also consider the relatively high proportion of respondents who have not participated in any form of internationalization and do not intend to do so in the future. This may reflect a lack of motivation, limited awareness of the potential benefits, or concerns related to language, formal procedures, and other challenges. It may also indicate a low sense of agency and insufficient institutional support from the university. Respondents pointed out that the most common forms of international engagement among academic staff are participation in international scientific conferences and publishing in foreign academic journals.

The conducted research allowed for the formulation of the following conclusions:

- The development of university internationalization should begin with the creation of a dedicated internationalization strategy, including specific systemic solutions and clearly defined sources of funding.
- A key stage in the internationalization process is the development of a comprehensive educational and research offer targeted at foreign audiences, along with the planning of promotional campaigns in international markets.
- Another important phase involves formal and administrative preparation, i.e., the establishment of recruitment procedures for international students and academic staff, as well as the simplification of processes related to the signing of cooperation agreements and reception conditions in Poland.
- University authorities should take action to educate staff in order to improve their foreign language proficiency (as indicated by 51% of respondents) and to raise awareness of the available forms of engagement in international exchange (mentioned by 40% of respondents).
- It is essential to introduce motivation systems and provide organizational and financial support, particularly for those staff members who are still inactive in the area of internationalization.
- Universities should address the issue of funding for international mobility of academic staff (as indicated by 71% of respondents), including full or partial funding for participation in research fellowships, study tours, international conferences, and visiting professorships.
- Staff also expect the university to provide support in the preparation of international project applications (as indicated by 62% of respondents).
- Furthermore, respondents emphasized the importance of increasing the number of international students (noted by 56% of respondents) and engaging international faculty in both teaching and research activities (mentioned by 53%) as key elements for strengthening institutional internationalization.
- In order to enhance staff engagement in internationalization efforts, universities should address the issue of work overload and introduce incentive systems, as 44% of respondents identified excessive workload and lack of time as major barriers.

The greatest expectations expressed by the respondents concern the practical presence of internationalization at the university, including a greater number of courses taught in English, as well as an increase in the number of international students and staff.

In summary, the results of the study clearly indicate the need for a range of improvements in the university's approach to internationalization. According to the academic staff, the current state of internationalization is inconsistent, insufficiently supported, and lacking a systemic structure. University authorities should particularly focus on increasing staff interest in participating in international mobility programs by implementing support mechanisms and

introducing appropriate organizational, financial, and administrative solutions. Respondents tend to view internationalization as an additional burden rather than an integral part of academic work. Therefore, it is essential to introduce systematic support and meaningful incentives for academic staff to reduce their sense of isolation in international activities. University leadership should reflect on how to change the perception among academic staff that internationalization efforts are low-reward and carry high organizational risk. Support for researchers should focus on facilitating mobility, encouraging participation in international projects, and recognizing their efforts in performance evaluations and incentive systems.

6. Recommendations

In order to effectively support the internationalization process at universities, a set of coordinated actions may be implemented across three key areas: policy changes, training programs, and administrative reforms.

First of all it is recommended to develop and implement a comprehensive internationalization strategy which would be closely aligned with the institution's development goals. Such a strategy must include clearly defined performance indicators, quantitative and qualitative targets as well as designated sources of funding.

It is also important to introduce motivation systems and to include international engagement as a component of the academic staff performance evaluation and promotion criteria.

The university should launch regular training programs. These should include the development of language competencies - particularly in academic English, as well as training on intercultural communication and teaching in international environments.

Worth considering is also the introduction of changes in administrative support area. In particular, procedures related to international cooperation, such as signing agreements, recruiting international students and staff, and supporting foreign guests. These processes shall be simplified and carried out with significant support from administrative staff. A recommended solution would be to establish a Welcome Center that provides comprehensive support to both staff and students.

Moreover, it is important to strengthen organizational and substantive support for employees planning to participate in international projects, especially in the preparation and submission of grant applications. Staff also pointed to the need to increase the number of international students and to involve more international faculty members in both research and teaching activities.

Finally, it should be emphasized that reducing excessive workload and better communication regarding the benefits of internationalization can significantly increase academic staff engagement in this area. Therefore, the introduction of effective incentive

systems and improved internal communication should be integral elements of the university's strategy.

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References

1. Akademia WSB (2025). Retrieved from: https://wsb.edu.pl/en/student/international-office/international-events/silesian-sustainable-business-summer-university, 19.05.2025.
2. Akademia WSB (2025). Retrieved from: https://wsb.edu.pl/en/student/news/become-a-buddy-mentor-at-wsb-university.html, 20.05.2025.
3. Altbach, P.G., Knight, J. (2007). The internationalization of higher education: Motivations and realities. *Journal of Studies in International Education, 11(3-4),* pp. 290-305.
4. Bakay, M. E. (2023). Multicultural Classrooms in European Higher Education: Findings from Interviews with International students and Teaching Staff. *International Journal of Lifelong Education and Leadership*, pp. 1-16.
5. Bedenlier, S., Zawacki-Richter, O. (2015*).* Internationalization of higher education and the impacts on academic faculty members. *Research in Comparative & International Education, vol. 10(2),* pp. 185-201.
6. Bradshaw, T., Curtis, M. (2023). Faculty of Constructions of Internationalization: Practice and Perception in Omani Higher Education. *Journal of Comparative & International Higher Education, vol. 16, iss. 5,* pp. 132-144.
7. Brandenburg, U., de Wit, H. (2011). The end of internationalization. *International Higher Education*, *62*, pp. 15-17.
8. Chen, K., Ding, Y., Zhao, B., Guo, R., Ning, L. (2025). Benefits beyond the local network: Does indirect international collaboration ties contribute to research performance for young scientists? *Research Policy, 54*, pp. 1-19.
9. De Wit, H. (1999). Changing Rationales for the Internationalization of Higher Education. *International Higher Education*, *15*, pp. 2-3.
10. De Wit, H. (2002). *Internationalization of higher education in the United States of America and Europe: A historical. Comparative and conceptual analysis*. Greenwood Press.

11. De Wit, H. (2013). Reconsidering the Concept of Internationalization. *International Higher Education, No. 70*, pp. 6-7.
12. De Wit, H., Hunter, F. (2015). Understanding Internationalisation of higher education in the European context. In: A. Curaj, L. Matei, R. Pricopie, J. Salmi, P. Scott (eds.), *The European Higher Education Area* (pp. 41-58). Springer.
13. Dusdal, J., Powell, J.W. (2021). Benefits, Motivations, and Challenges in International Collaborative Research: A Sociology of Science Case Study. *Science and Public Policy, 48(2),* pp. 235-245.
14. ECORYS Sp. z o.o. (2020), Ewaluacja interwencji wspierających umiędzynarodowienie, zmiany organizacyjne i rozwój kompetencji kadr uczelni, realizowanych w ramach Działań 3.3 (Umiędzynarodowienie polskiego szkolnictwa wyższego) oraz 3.4 (Zarządzanie w instytucjach szkolnictwa wyższego) Retrieved from: https://www.ewaluacja.gov.pl/media/94281/RK_rozwoj_kompetencji_kadry_uczelni.pdf, 20.05.2025.
15. EUA (2025). Retrieved from: https://www.eua.eu/our-membership/member-directory.html, 19.05.2025.
16. Gdańsk University of Technology (2025). Retrieved from: https://pg.edu.pl/en/research/research-projects, 20.05.2025.
17. Green, W., Whitsed, C. (Eds.) (2015). *Critical perspectives on internationalising the curriculum: Reflective narrative accounts from business, education and health*. Sense.
18. Guri-Rosenblit, S. (2015). Internationalization of Higher Education: Navigating Between Contrasting Trends. In: A. Curaj, L. Matei, R. Pricopie, J. Salmi, P. Scott (Eds.), *The European Higher Education Area* (pp. 13-26). Springer.
19. Healey, N. (2023). Reinventing international higher education for a socially just, sustainable world. *Perspectives: Policy and Practice in Higher Education*, *27(1),* pp. 1-10.
20. Hudzik, J.K. (2011). *Comprehensive internationalization: From concept to action.* NAFSA: Association of International Educators.
21. *Internatowy System Aktów Prawnych*. Retrieved from: https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20250000619/O/D20250619.pdf, 19.05.2025.
22. Jones, E., Leask, B., Brandeburg, U., de Wit, H. (2021). Global Social Responsibility and the Internationalisation of Higher Education for Society. *Journal of Studies in International Education, 25(4),* pp. 330-347.
23. Karaferye, F. (2019). Academic Internationalization: Academics as Marketing Actors in Higher Education. *International Journal of Social Sciences and Education Research, vol. 5(10),* pp. 16-22.
24. Knight, J. (2013). The changing landscape of higher education internationalisation – for better or worse? *Perspectives: Policy and Practice in Higher Education*, *17(3),* pp. 84-90.

25. Knight, J. (2003). Updating the Definition of Internationalization. *International Higher Education, No. 33*, pp. 2-3.
26. Knight, J. (2004). Internationalization remodeled: Definition, approaches, and rationales. *Journal of Studies in International Education, 8(1),* pp. 5-31.
27. Knight, J. (2015). Updating the definition of internationalization. *International Higher Education*, *33*, pp. 2-3.
28. Knight, J. (2021). Higher Education Internationalisation: Concepts, Rationales and Frameworks. *Revista Redalint, 1(1),* pp. 65-88.
29. Komisja Europejska, Uniwersytety Europejskie. Retrieved from: https://education.ec.europa.eu/education-levels/higher-education/european-universities-initiative, 20.05.2025.
30. Komitet Polityki Naukowej MEiN (2021). *Stanowisko Komitetu Polityki Naukowej w sprawie działań niezbędnych do rozwoju umiędzynarodowienia nauki i szkolnictwa wyższego w Polsce.*
31. Koźmiński University (2025). Retrieved from: https://www.kozminski.edu.pl/en/programs, 20.05.2025.
32. Leask, B., Gayardon, A. (2021). Reimagining Internationalization for Society. *Journal of Studies in International Education, 25(4),* pp. 323-329.
33. Mananay, J., Sanchez, J.M.P., Boholan, H., Beltran, N.Y. (2024). Patterns and Pathways: Teacher's Perceptions, Readiness, Support and Barrirs to Internationalization in Higher Education. *International Journal of Learning, Teaching and Education Research, vol. 23, No. 9*, pp. 401-431.
34. Marginson, S., van der Wende, M. (2007). Globalisation and higher education. *OECD Education Working Papers, No. 8*.
35. Marinoni, G., Pina Cardona, S.B. (2024). *Internationalization of Higher Education: Current Trands and Future Scenarios*. 6th IAU Global Survey Report.
36. Mbachi, R.M. (2025). Bridging borders: Global insights and challenges in internationalising higher education using a decade-long case study. *International Journal of Educational Research Open, vol. 8,* pp. 1-8.
37. Medical University of Gdańsk (2019). Retrieved from: https://mug.edu.pl/59025.html, 20.05.2025.
38. Ministerstwo Nauki I Szkolnictwa Wyższego. *Proces Boloński*. Retrieved from: https://www.gov.pl/web/nauka/proces-bolonski, 20.05.2025.
39. Mittelmeier, J., Rienties, B., Gunter, A., Raghuram, P. (2021). Conceptualizing internationalization at a distance: A "third category" of university internationalization. *Journal of Studies in International Education*, *25(3),* pp. 266-282.
40. Narodowa Agencja Wymiany Akademickiej. Retrieved from: https://nawa.gov.pl/naukowcy/ceepus, 19.05.2025.

41. Narodowa Agencja Wymiany Akademickiej. Retrieved from: https://nawa.gov.pl/promocja-i-targi/targi, 19.05.2025.
42. Narodowe Centrum Badań i Rozwoju (2007). Retrieved from: https://www.gov.pl/web/ncbr, 20.05.2025.
43. Narodowe Centrum Nauki (2010). Retrieved from: https://ncn.gov.pl/, 20.05.2025.
44. Neale, R.H., Spark, A., Carter, J. (2018). Developing internationalisation strategies. *International Journal of Educational Management, 32(1).* UK: University of Winchester, pp. 171-184.
45. Niemiecka Agencja Wymiany Akademickiej. Retrieved from: https://www.daad.pl/pl/, 20.05.2025.
46. Perspektywy. Retrieved from: https://perspektywy.pl/portal/index.php?option=com_content&view=article&id=10407&catid=24&Itemid=119, 19.05.2025.
47. Płoszaj, A. (2023). *Raport z badania potencjału szkół wyższych i instytucji naukowych do przyjmowania osób z zagranicy.* NAWA
48. Polsko-Amerykańska Komicja Fulbrighta. Retrieved from: https://fulbright.edu.pl/, 20.05.2025.
49. Popowska, M. (2016). Internacjonalizacja szkolnictwa wyższego – uwarunkowania i przejawy w świetle faktów i liczb. *Horyzonty wychowania*, pp. 313-154.
50. Poznań University of Economics and Business (2025). Retrieved from: https://amu.edu.pl/en/news-and-events, 20.05.2025.
51. Prieto-Gutierrez, J.J. (2024). The internationalization of higher education beyond 2030. *Journal of Higher Education Policy and Leadership Studies, 5(3),* pp. 193-198.
52. Program Erasmus +. Retrieved from: https://erasmusplus.org.pl/, 19.05.2025.
53. Program Socrates. Retrieved from: https://cordis.europa.eu/programme/id/ET-SOCRATES-1/pl, 20.05.2025.
54. Program TEMPUS. Retrieved from: https://cordis.europa.eu/article/id/31-transeuropean-mobility-for-university-studies-tempus, 20.05.2025.
55. Robson, S. (2022). Internationalization: A transformative agenda for higher education? *Teachers and Teaching*, 17(6), pp. 619-630.
56. Robson, S., Wihlborg, M. (2019), Internationalisation of higher education: Impacts, challenges and future possibilities. *European Educational Research Journal*, *18(2),* pp. 127-134.
57. SGH Warsaw School of Economics (2025). Retrieved from: https://www.sgh.waw.pl/en/educational-offer/postgraduate-and-mba-studies, 20.05.2025.
58. Shih, T., Gaunt, A., Ostlund, S. (2020). Responsible internationalisation: Guidelines for reflection on international academic collaboration. Stockholm: *STINT*.
59. Shih, T. (2024). The role of research funders in providing directions for managing responsible internationalization and research security. *Technological Forecasting and Social Change, vol. 201*, pp. 1-10.

60. Stier, J. (2004). Taking a critical stance toward internationalization ideologies in higher education: Idealism, instrumentalism and educationalism. *Globalisation Societies and Education*, *2(1),* pp. 83-97.
61. Study in Poland. Retrieved from: https://study.gov.pl/, 19.05.2025.
62. Study in Pomorskie. Retrieved from: https://gospodarka.pomorskie.eu/study-in-pomorskie/, 19.05.2025.
63. Teichler, U., (2004). The changing debate on internationalisation of higher education. *Higher Education, 48(10),* pp. 5-26.
64. Tight, M. (2021). Globalization and Internationalization as Frameworks for Higher Education Research. *Research Papers in Education*, 36(1), pp. 52-74.
65. Universities UK (2022). *Managing risks in international research and innovation. An overview of higher education sector guidance.* Woburn Houce.
66. University of Economics and Human Sciences in Warsaw (2023). Retrieved from: https://vizja.pl/podwojny-dyplom-i-wymiana-studencka-do-listy-partnerow-aeh-dolaczylo-kilka-krajow/, 19.05.2025.
67. University of Gdańsk (2025). Retrieved from: https://ug.edu.pl/news/en/8447/ug-equality-day-university-gdansk-celebrates-equality-and-inclusivity-science, 19.05.2025.
68. University of Gdańsk Doctoral School (2025). Retrieved from: https://sd.ug.edu.pl/en/biotechnologia/glowna
69. University of Warsaw (2024). Retrieved from: https://en.uw.edu.pl/2nd-congress-of-internationalisation/, 19.05.2025.
70. Ustawa prawo o szkolnictwie wyższym i nauce (2018). Retrieved from: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20180001668, 19.05.2025.
71. Van den Hende, F., Riezebos, J. (2023). Academic staff on their engagement with curriculum internationalisation: an organisattional change perspective. *Higher Education Research & Development*, *vol. 42, No. 5*, pp. 1247-1266.
72. van den Hende, F., Whitsed, C., Coelen, R.J. (2022). An organizational change perspective for the curriculum internationalization process: Bridging the gap between strategy and implementation. *Journal of Studies in International Education*, *vol. 27*, pp. 520-538.
73. Wąsikiewicz-Firlej, E., Szczepaniak-Kozak, A., Lankiewicz, H. (2022), *Doświadczenie pobytu w Polsce w narracjach zagranicznych studentów.* FRSE.
74. Wilins, S., Huisman, J. (2012). Student Satisfaction and Student Perception of Quality at International Branch Campuses in the United Arab Emirates. *Journal of Higher Education olicy and Management*, *34(5),* pp. 543-556.
75. Wrocław University of Science and Technology (2025) Retrieved from: https://crm.pwr.edu.pl/en/, 20.05.2025.
76. Zelenkova, A. et al. (2019). Intercultural competence of university teachers: a challenge of internationalization. *Journal of Language and Cultural Education*, *7(1),* pp. 1-18.

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DECISION OF DIETARY SUPPLEMENT CONSUMERS IN THE B2C MARKET BY NEEDS, MOTIVATIONS AND PURCHASE PREFERENCES

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Purpose: The consumption of dietary supplements around the world is constantly increasing, and this trend is observed in all countries that provide data in this area. Consumer spending on dietary supplements is becoming an important source of government revenue, and the long-term consumption increase indicates a lasting change in consumer behaviour. The authors attempted to identify the sources of dietary supplement consumer decisions, examining them in the context of market segmentation based on needs, motivations and purchase preferences. The aim of this paper is to determine the factors that influence the purchasing decisions of dietary supplement consumers in the B2C market, taking into account three categories: needs, motivations and purchase preferences.
Design/methodology/approach: The research was conducted based on a literature review which allowed for identifying the key determinants influencing purchasing decisions in this market segment.
Findings: The results provide important information for both marketing practitioners and researchers in the dietary supplement market, pointing to the variety of motives that shape consumer behaviour and the need for a balanced and informed exploration of this market.
Originality/value: This article presents a structured analysis, including an original synthesis, concerning the sources of decision-making by consumers in the B2C market, taking into account their needs, motivations, and purchasing preferences (referred to as "factors shaping types of dietary supplement consumers"). The results of the study can be used in a versatile manner—both by researchers in the field (as a basis for conducting original studies) and by managers to support the development of organizational management strategies in this area.
Keywords: dietary supplements, purchasing decisions, needs, motivations and purchase preferences, B2C market.
Category of the paper: research paper.

1. Introduction

The consumption of dietary supplements around the world is constantly increasing, and this trend is observed in all countries that provide data in this area (Report 1, 2024; Report 2, 2025; Report 3, 2024). *The dietary supplements market is on an upward trend both in terms of consumption and in its increasing share in national budgets* (Report 4, 2025; Report 5, 2024).

Consumer spending on dietary supplements is therefore becoming an important source of revenue for the state budget, and the long-lasting trend of increasing consumption points to a permanent change in consumer behaviour. This change, due to its extent and consequences for consumers, is an important and scientifically interesting research topic. Therefore, the authors identified the key factors characterising dietary supplement consumers and, as a result of their research, attempted to identify the sources of dietary supplement consumer decisions in terms of market segmentation factors and the corresponding specific criteria. It was assumed that the dietary supplement market's segmentation factors would be extracted for three main categories, *i.e.* consumer needs, motivations and purchase preferences.

With reference to the above, this paper focuses on the issues for the following research problem: *what sources of consumer decisions for dietary supplements in the B2C market can be distinguished? The research was restricted to a logical sequence of concepts: needs-motivations-preferences of dietary supplement consumers* (hereafter: factor categories). The following specific questions were defined for the formulated problem:

Q1) *What needs do dietary supplement consumers demonstrate in the B2C market?*

Q2) *What purchase motivations do dietary supplement consumers demonstrate in the B2C market?*

Q3) *What purchase preferences do dietary supplement consumers demonstrate in the B2C market?*

In view of the above, the authors of this publication defined the aim of the paper as to *systematise knowledge in terms of identifying the factors underlying the differentiation of the sources of dietary supplement consumer decisions in the B2C market*.

It should be noted that the research conducted by the authors is new. Its results provide the basis, on both a scientific and practical level, for an informed and sustainable exploration and exploitation of the dietary supplement market, particularly from the view-point of individual consumers (B2C).

2. Materials & Methods

A literature review procedure was applied in accordance with Hart and Chakon's methodology in order to achieve the defined research objective.

Both Hart and Czakon proposed a systematic algorithm that should be followed in order to properly conduct a literature review in a given research area (Hart, 1998; Czakon, 2011). The methodology contains a five-part procedure to follow, including:

stage 1 – data identification and collection,

stage 2 – data assessment and verification,

stage 3 – bibliometric analysis,

stage 4 – visualization,

stage 5 – interpretation and description of results (Figure 1).

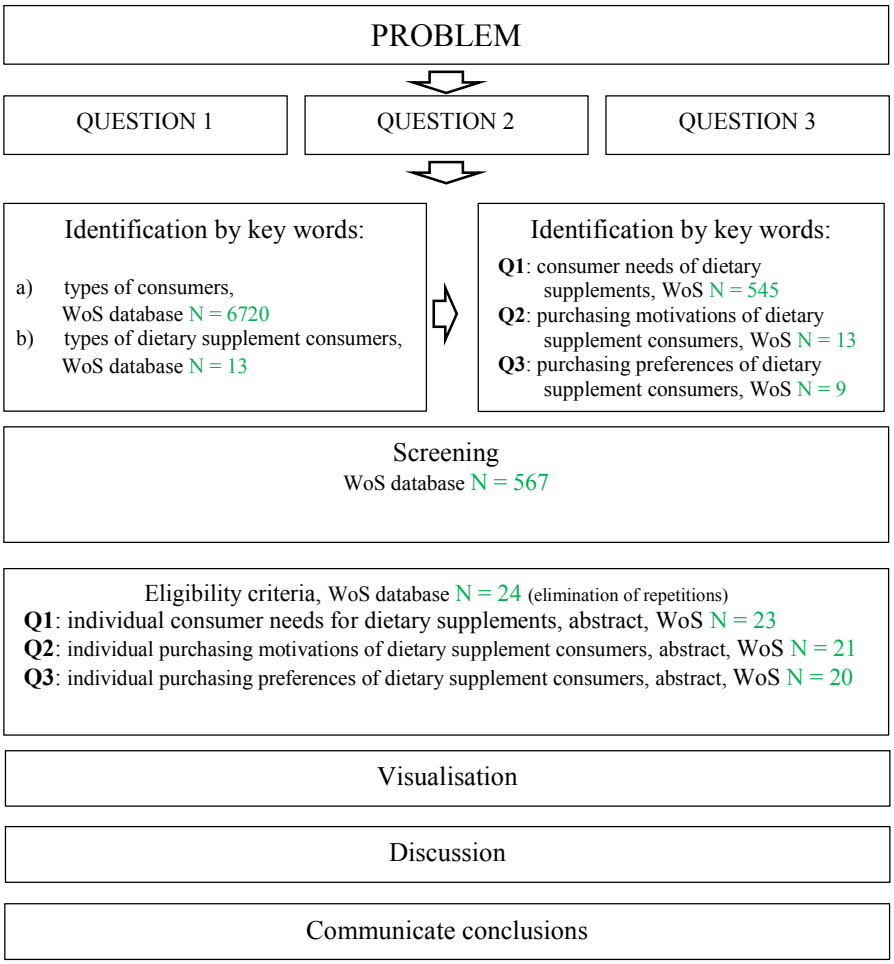

Figure 1. Literature review procedure (as of 28/02/2025).

Source: own study.

Stage 1 of the procedure, i.e. data identification and collection, was undertaken for the formulated research problem and the three research questions (Q1, Q2, Q3). In order to identify thematic scientific publications, the authors used the Web of Science (WoS) bibliographic

database, which is one of the recommended repositories for scientific publications (Munn et al., 2018; Kumar, 2021; Czakon et al., 2023; Azarian et al., 2023). The authors distinguished 6733 publications based on the selected keywords "types of consumers" and "types of dietary supplement consumers".

A database of 567 papers was generated in the next stage of publication selection. The authors focused on the keywords assigned to each specific question, i.e.: "dietary supplement consumer needs" (Q1), "purchasing motivations of dietary supplement consumers" (Q2) and "purchasing preferences of dietary supplement consumers" (Q3). The main objective of the stage called early screening was to eliminate papers with a weak thematic link to the research questions. This resulted in another elimination of documents that were not related to the defined scientific problem.

In the next step of publication selection, a database of 24 papers was generated according to the logical key adopted. At this stage, the keywords were made more specific and, at the same time, the authors focused on the content of abstracts of papers published in English – mapped to specific questions, i.e.: "individual consumer needs for dietary supplements" (Q1), "individual purchasing motivations of dietary supplement consumers" (Q2) and "individual purchasing preferences of dietary supplement consumers" (Q3). The time range was not restricted, but the search provided papers created between 1995-2024. An additional criterion for the selection of thematic publications was the document type. Journal articles, conference papers, chapters in books and books were selected. Ultimately, titles, keywords and abstracts were reselected, and all publications that were repetitive, unrelated or did not address the types of dietary supplement consumers were eliminated. After all criteria had been met, 24 documents remained to be analysed. The final stage of the analyses presented a visualisation of the research in the form of a drawing (Fig. 2) and, at a later stage, a discussion of the analysis results in accordance with the adopted methodology.

3. Results

The main source of knowledge concerning the types of dietary supplement consumers is the literature on management and, in particular, marketing in its broadest sense. This type of literature focuses on customer issues (Sweeney, Soutar, 2016; Schiffman, Kanuk, 2020; Lamb et al., 2020; Solomon, 2021; Babin et al., 2021). Due to the scientific problem studied, the authors' research was focused on the areas of: *needs, motivations and purchase preferences of dietary supplement consumers on the Polish market* (Figure 2).

Ph. Kotler defines a human *need as the state of feeling unfulfilled* (Kotler et al., 1999; Tao et al., 2009; de Souza et al., 2010). Extending this definition to *consumer needs*, it is possible to assume that they present a state of psycho-physical and/or spiritual discomfort that stems from a sense of absence.

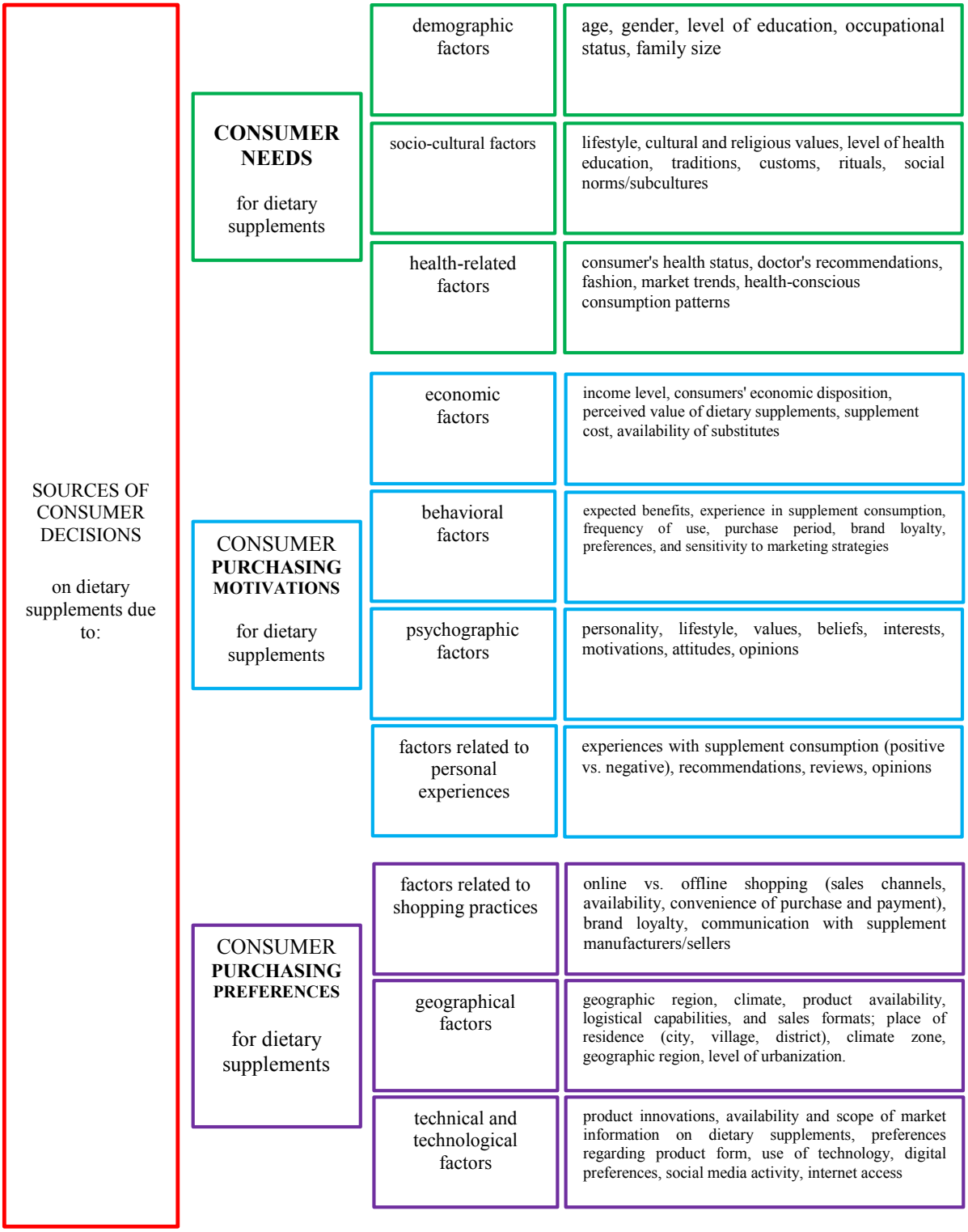

Figure 2. Factors shaping types of dietary supplement consumers.

Source: own study based on: (Arora, Gupta, 2021; Babin et al., 2021; Blackwell et al., 2021; Burgiel, Zrałek, 2010; Hoyer et al., 2020; Schiffman, Kanuk, 2020; Solomon, 2021; Sweeney, Soutar, 2001; Choi, Park, 2020; Sharma, Yadav, 2023).

Continuing with the accepted line of reasoning, the authors assume that ***the consumer need for dietary supplements*** reflects the perceived state of psycho-physical and/or spiritual discomfort that results from the lack of consumption of dietary supplements (Hys, 2018). In this category, dietary supplement consumers most often indicate needs that are directly related to supplementing their own diet, improving their general psycho-physical condition, health-promoting prevention, or compensating for nutritional deficiencies due to illness or recovery (Hys, 2020). In order to identify the types of dietary supplement consumers, it is crucial to extend the analysis of customer needs to further issues, such as their *motivations and purchase preferences* (Figure 2).

Consumer behaviour is influenced by factors that, arranged in semantic groups, are recorded, among others, in the following models:

A model of factors influencing consumer behaviour (Kotler, 1999, p. 161; Noor et al., 2014*)*:

a) cultural factors (culture, subculture, social class),
b) social (reference group, family, role and status),
c) personal (age and life stage, occupation, economic situation, lifestyle, personality and life ambitions),
d) psycho-social (*motivation*, perception, learning process, beliefs and attitudes).

A model of factors shaping consumer behaviour (Burgiel, Zrałek, 2010):

a) objective, economic: internal (level and sources of income, credit, savings, durable goods, level and structure of consumption), external (supply, level and relationship of prices, trade and service infrastructure, sales policy information system, general economic situation of the country),
b) objective, non-economic:
   – internal (*demographic* such as age, gender, marital status, household size and *socio-professional* such as level and type of education, and *social*, i.e. family, reference group),
   – external (*geo-environmental* such as geographical location, place of residence, climate, environmental conditions, degree of pollution, and *civilisational-cultural*, i.e. culture and subculture),
c) subjective, psychological, including: *motives*, habits, perception, learning process, habits, emotions, attitudes, personality, private information, habits.

Among the multitude of determinants of consumer behaviour in the market, it is important to note the ***motives and purchase motivations*** of consumers, which are mentioned at the psycho-social and psychological levels (Burgiel, Zrałek, 2010; Kotler, 1999; Carrasco et al., 2012; Blanco Gonzalez, 2012; Bharadwaj, 2022). Thus, it can be assumed that purchasing motivations reflect the consumers' psycho-social and psychological reasons which determine their purchase of dietary supplements. This category lists many sources of motivation for dietary supplement consumers arising from beliefs, experiences and their emotions (Hys et al., 2022; Eldesouky et al., 2020; Song et al., 2022). Some of the motivations include:

- improving the quality of nutrition – supplementing the daily diet with missing ingredients,
- supporting the body's functioning in terms of psycho-physical and emotional well-being, including stress reduction,
- improving the quality of life – by influencing their physical appearance.

In contrast, from the view-point of the ***purchase preferences*** of dietary supplement consumers, it should be assumed that these reflect their individual choices (Kaminski et al., 2021). Dietary supplement consumers individually identify sets of preferred characteristics of dietary supplements that directly influence purchasing decisions. The source of purchase preferences of dietary supplement consumers can be traced back to a variety of levels and may result from the priorities adopted by consumers in terms of the brand of dietary supplements, their country of production, the form of the product offered (e.g. liquid, solid, aerosol), price, availability, environmental aspects, or opinions and recommendations (Hys, Koziarska, 2020, 2021; Trajanovska et al., 2010; Curdova, Lostakova, 2012).

As a consequence of the analysis carried out, it is important to make a conscious distinction between the concepts of needs, motivations and purchase preferences of dietary supplement consumers. The fundamental difference between these concepts is derived, among others, from the following (Kotler, 1999; Kotler, Keller, 2021; Tanner, Raymond, 2020; Warinthaksa et al., 2024; Corbett et al., 2024)*:*

1. The nature of needs – these are usually general in nature and focus on requirements that demonstrate a nutritional or other physiological effect.
2. The sources of dietary supplement consumers' purchase motivations – they reflect the intrinsic reasons for their purchases, taking into account a range of the consumers' psycho-social and psychological factors (e.g. personal goals, emotional states, or lifestyles).
3. The purchase preferences, which result from a defined set of specific characteristics belonging to the dietary supplements in question that influence consumer decisions (e.g. form, administration method, brand).

As a consequence of the research – focusing on market segmentation factors – the authors defined the following structure taking into account the types of dietary supplement consumers (Figure 2).

4. Discussion

In an attempt to identify the factors differentiating dietary supplement consumers, the authors focused on three main categories forming a logical sequence of concepts, i.e. needs – purchase motivations – purchase preferences (Q1 – Q2 – Q3).

Assigning the identified factors to the identified conceptual groups (needs – motivations – preferences) was not a straightforward task due to different opinions among researchers (Choi, Park, 2020).

4.1. Determinants influencing the perception of need of dietary supplement consumers (Q1)

Needs are general in nature and stem from the perceptions of dietary supplement consumers. Consumers wishing to make positive changes in their lives in terms of prevention, maintenance and/or improvement of their health and quality of life take a number of measures to counterbalance their discomfort in this regard (Kotler, 1999; Hys, 2018, 2020). Accordingly, the authors assigned demographic, socio-cultural and health-promoting factors to the category of purchasing needs.

Demographic factors provide the criteria for the basic classification of dietary supplement consumers. This is related to the fact that criteria such as age, gender or health status and general psycho-physical and spiritual condition directly influence the perceived needs of consumers (Reid et al., 2014; Hys, 2020).

The issue of age is raised in literature as a key determinant in the distribution of dietary supplement consumers. Infants, children, adolescents, adults and the elderly have different needs for supplements – both in terms of the type of supplement and the functions it should perform (DiNicolantonio, O'Keefe, 2023). Vitamins supplemented in each age group can be provided as an example, however these differ in terms of type and concentration, such as:

- in infants (0-12 months), due to the limited capacity for absorption of certain vitamins with food, mainly vitamins A, B12, D, K are supplemented, because they are essential for their proper growth and further development (Kędzierska, 2017; Szymański, Dąbrowska, 2015),
- in children (1-12 years of age), supplementation with vitamins A, B6, B12, C, D is recommended in order to ensure the proper development of the immune and nervous systems, among others (Szymański, Dąbrowska, 2015; Radhakrishnan, 2018),
- in adolescents (13-18 years of age), supplementation with vitamins A, B9, B12, C, D is recommended in order to ensure proper development of the skeletal system, among others (Szymański, Dąbrowska, 2015; Radhakrishnan, 2018),
- in adults (19-64 years of age), supplementation with vitamins B6, C, D, E is recommended in order to ensure the proper functioning of the immune system, prevent osteoporosis, oxidative stress and support metabolism, among others (Witkowska, Król, 2019; Matusiak, 2018),
- in the elderly (64+), supplementation with vitamins B12, C, D, E is recommended to support the proper body functioning (Kohlmeier, 2015; Hochberg, 2015; Michałowicz, Binkowska, 2020; Shah, Binns, 2022; Michałowicz, Binkowska, 2022; Manson, Bassuk, 2025).

Socio-cultural factors influence the perceived needs of dietary supplement consumers in relation to traditions, regional culture, social beliefs (Yang, Wang, 2015). The approach to the origin of dietary supplements – natural or pharmacological – can be provided as an example (McCarty, 2009; Sharma, Yadav, 2023). Reference to in dietary supplement ingredients, e.g. vegan, halal.

Health-promoting factors, on the other hand, shape the needs of dietary supplement consumers by their approach to maintenance, prevention or taking care of their health. Examples include supplements that support systems (e.g. immune, circulatory, bone) or human body functions (e.g. improving sleep quality, sexual function) (Fitzgerald, Michael, 2000).

4.2. Determinants influencing motivations of dietary supplement consumers (Q2)

Determinants of consumer purchase motivations reflect the reasons that lead dietary supplement consumers to decide to purchase a particular product. Motivations are a set of factors that derive from the goals defined by the consumer, the experiences he or she has (both positive and negative) and the beliefs and values he or she presents.

In a detailed manner, it can be assumed that:

- economic factors (Wardle et al., 2000), including income, determine the consumers' financial accessibility to particular dietary supplements (e.g. basic supplements vs luxury supplements; using special offers for one-off larger orders),
- behavioural factors (Kramer et al., 2004) are usually results of consumer habits (e.g. brand loyalty, frequency of consumption, set goal, determination),
- psychographic factors (Keller et al., 2015) stem from the personality of dietary supplement consumers and are related to the personal values and beliefs they present (e.g. eating habits, health and nutrition priorities; concern for environmental impact, i.e. type of biodegradable or non-biodegradable packaging),
- factors related to personal experience (Arnett et al., 2006**)** usually stem from the consumers' previous experience with the dietary supplements in question and influence their ability to assess their suitability, efficacy and nutritional or physiological effectiveness.

4.3. Determinants influencing purchase preferences of dietary supplement consumers (Q3)

A number of factors influence the purchase preferences of dietary supplement consumers. These include technical and technological factors, those related to purchasing practices and those resulting from their geographical location.

Technical and technological factors (Boudet et al., 2012) are those related to the consumers' ability to use technology and the capabilities of ICT systems (e.g. online shopping, payment solutions, convenience of purchase). In addition, they may relate to technical and technological

solutions used by dietary supplement manufacturers for supplement applications (e.g. used to support monitoring of supplement consumption by consumers).

Dietary supplement consumers have different purchasing practices (Kim et al., 2011) resulting from the evaluation system they use to select a product. They arise from tastes, preferences or certain behavioural disorders (e.g. phobias). Consumers pay attention to the availability of supplements (e.g. 24/7) or the additional expert services offered (e.g. advice from pharmacists).

The last group of factors are geographical factors (Wigand, 2004) which determine the behaviour of dietary supplement consumers by their geographical location. The location may influence the awareness of dietary supplement consumers (e.g. residents of small towns and big agglomerations show different purchase preferences).

5. Discussion

In this paper, the authors have attempted to identify the sources of decisions of individual dietary supplement consumers (constituting B2C market customers). An analysis of the subject literature allowed the authors to identify the main *categories that constitute the source of consumers' purchasing decisions, i.e.* the needs, motivations and purchase preferences of dietary supplement consumers.

The authors assigned a number of specific criteria to the sources of purchasing decisions thus defined. They were able to establish the following: *What purchase preferences do dietary supplement consumers demonstrate in the B2C market?*

The authors found that the allocation of factors to the different groups was due to the following:

- Consumer needs understood as a set of health, demographic and social aspects that determine the purchasing decisions of dietary supplement consumers.
- Purchase motivations that stem from emotions, beliefs, experiences and technology (mainly digital), which are responsible for the consumer's choice of a particular dietary supplement.
- Purchase preferences are an important and a complex set of criteria used by the consumer to choose dietary supplements.

Each of the above-mentioned factors is driven by different conditions, making in-depth research in this field fundamental to understanding changes and trends in the dietary supplement market.

Thus, the authors systematised the scattered knowledge on identifying the factors underlying the differentiation of the sources of dietary supplement consumer decisions in the B2C market. Furthermore, they proposed an original classification of these factors with the identification and description of the different criteria describing them.

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References

1. Aaker, D.A., Kumar, V., Day, G.S. (2004). *Marketing Research*.
2. Arnett, C., Brown, R., Walker, D. (2006)**.** Personal Experiences and Health Supplement Use: Evidence from Longitudinal Data*. Public Health Nutrition, 9(5),* 415-425.
3. Arora, A., Gupta, A. (2021). *Consumer Behavior: Insights for Marketing Strategy*. Springer.
4. Babin, B.J., Harris, E.G., Zinkhan, G.M. (2021). *Consumer Behavior* (8th ed.). McGraw-Hill Education.
5. Blackwell, R.D., Miniard, P.W., Engel, J.F. (2021). *Consumer Behavior* (11th ed.). Cengage Learning.
6. Boudet, L., Peltier, C. (2012)**.** The Impact of Technological Innovation on Supplement Purchases*. Journal of Health Technology, 24(3),* 312-327.
7. Burgiel A., Zrałek J. (2010). Potrzeby i zachowania konsumpcyjne oraz ich determinanty – podstawowe pojęcia. In: E. Kieżel (Ed.), *Konsument i jego zachowania na rynku europejskim* (pp. 32-47). Warsaw: PWE.
8. Choi, S.H., Park, Y. (2020). Cultural Differences in Supplement Preferences: A Comparative Study. *International Journal of Consumer Studies*.
9. Czakon, W. (2011). Metodyka systematycznego przeglądu literatury. *Przegląd Organizacji, No. 3(854),* 57-61, doi.org/10.33141/po.2011.03.13.
10. Fitzgerald, L., Michael, M. (2000)**.** Health, Wellness, and Consumer Behavior: The Role of Supplements in the Healthier Lifestyle*. Journal of Health Marketing, 23(1),* 45-57.
11. Hart, C. (1998). *Doing a literature review: Releasing the social science research imagination.* London: SAGE Publications.
12. Hoyer, W.D., MacInnis, D.J., Pieters, R. (2020). *Consumer Behavior* (7th ed.). Cengage Learning.
13. Hys, K., Matuszek, D., Olejnik, K., Bierczyński, K. (2022). Intensity of Commercial Communication in Poland in the Field of Dietary Supplements. *European Research Studies Journal, Vol. XXV, Iss. 4,* 404-414, https://ersj.eu/journal/3089#.

14. Hys, K. (2018). Healthcare products and food supplements in Poland – a comparison. In: R. Ulewicz, B. Hadzima (Eds.), *12th International Conference Quality Production Improvement (QPI 2018, MATEC) 183(01006),* Doi: doi.org/10.1051/matecconf/201818301006.
15. Hys, K. (2020). Identification of the reasons why individual consumer purchase dietary supplements. In: W. Sroka (Ed.), *Perspectives on Consumer Behaviour. Theoretical Aspects and Practical Applications, Contributions to Management Science, series 1505*. Springer. Doi: 10.1007/978-3-030-47380-8_9.
16. Hys, K., Koziarska, A. (2020). Supply Analysis of Supplementary Products in Poland. *European Research Studies Journal, 23(1),* 549-571. DOI:10.35808/ersj/1777.
17. Hys, K., Koziarska, A. (2021). Supplementary Product Forms: Analysis of Polish Market Trends. *European Research Studies Journal, Vol. XXIV, Iss. 4B*, 982-996.
18. Keller, P., Simon, M. (2015)**.** Psychographic Variables in Health Supplement Consumption. *Journal of Consumer Behavior, 11(4),* 102-118.
19. Kim, Y., Park, S., Lee, J. (2011)**.** Consumer Preferences and the Purchase of Dietary Supplements in the Age of Digital Commerce. *Journal of Retailing, 87(3),* 211-229.
20. Kotler, P. (1999). *Marketing Management*. Warsaw: Felberg SJA.
21. Kotler, P., Keller, K.L. (2021). *Marketing Management* (15th ed.). Pearson.
22. Kramer, M., Jones, P., Russell, R. (2004)**.** Behavioral Patterns in Supplement Use: A Longitudinal Study. *Journal of Nutrition, 40(1),* 29-40.
23. Lamb, C.W., Hair, J.F., McDaniel, C.D. (2020). *MKTG* (13th ed.). Cengage Learning.
24. McCarty A.K. (2009). Nutritional and Health Benefits of Nutraceuticals**.**
25. Noor, N.A.M.N., Yap, S.-F., Liew, K.-H., Rajah, E. (2014). Consumer attitudes toward dietary supplements consumption: Implications for pharmaceutical marketing. *International Journal of Pharmaceutical and Healthcare Marketing, 8(1),* 6-26. https://doi.org/10.1108/IJPHM-04-2013-0019
26. Reid, S., Smith, A., Jones, R. (2014)**.** Demographic Determinants of Dietary Supplement Use in the United States: A Review. *Journal of Nutritional Science, 6(2),* 200-215.
27. Report 1: Research and Markets (2024, June 11). *Global dietary supplements market analysis report 2024, by ingredient (vitamins, minerals, probiotics), form (capsules, gummies, liquids), end user, application, type, distribution channel and region*. Research and Markets. https://www.researchandmarkets.com/reports/xyz
28. Report 2: *Dietary supplements market size, share & industry analysis, by type (vitamins, minerals, enzymes, fatty acids, proteins, and others), by form (tablets, capsules, liquids, and powders), by application (energy & weight management, bone & joint health, general health, immunity, brain & mental health, skin/hair/nails, cardiac health, healthy aging, and others), by end-user (children, adults, pregnant women, and geriatric), by distribution channel (supermarkets/hypermarkets, pharmacies, online, and others), and regional*

forecasts, 2024-2032. https://www.marketresearchfuture.com/reports/dietary-supplements-market-3252

29. Report 3: Research and Markets (2024, June 11). *Global dietary supplements market analysis report 2024, by ingredient (vitamins, minerals, probiotics), form (capsules, gummies, liquids), end user, application, type, distribution channel and region*. https://www.researchandmarkets.com/reports/123456
30. Report 4: Statista Research Department (2025, February 24). *Revenue of the vitamins & minerals market worldwide by country 2023*. Statista. https://www.statista.com/statistics/xyz
31. Report 5: Horizon Databook (2024). *Dietary supplements market size, share & trends analysis report by ingredient (vitamins, minerals, probiotics), by form (capsules, gummies, liquids), by end user, by application, by type, by distribution channel, by region, and segment forecasts, 2024-2030* (Report ID: 978-1-68038-919-7). Horizon Databook. https://www.horizondatabook.com/reports/xyz
32. Schiffman, L.G., Kanuk, L.L. (2020). *Consumer Behavior* (12th ed.). Pearson Education.
33. Sharma, L., Yadav, A. (2023). Role of Functional Foods in Human Health and Disease Prevention. In: M. Thakur, T. Belwal (eds.), *Bioactive Components*. Singapore: Springer. https://doi.org/10.1007/978-981-19-2366-1_14
34. Solomon, M.R. (2021). *Consumer Behavior: Buying, Having, and Being* (12th ed.). Pearson Education.
35. Sweeney, J.C., Soutar, G.N. (2016). Consumer Perceived Value: The Development of a Multiple Item Scale. *Journal of Retailing*, *76(1),* 39-57.
36. Tanner, J.F., Raymond, M.A. (2020). *Principles of Marketing* (8th ed.). McGraw-Hill Education.
37. Wardle, J., McKibbin, A. (2000)**.** Socioeconomic Factors in the Purchase of Dietary Supplements. *Journal of Consumer Research, 27(1),* 85-98.
38. Wigand, R. (2004)**.** Geographical and Sociodemographic Influences on Consumer Purchases of Supplements. *Journal of Marketing Research, 18(4),* 89-102.
39. Yang, X., Wang, Y. (2015)**.** Cultural Influences on Supplement Consumption: A Comparative Study. *International Journal of Consumer Studies, 39(3),* 130-141.

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STRATEGIC PLANNING AND PRINCIPLES OF INCLUSIVE JUST TRANSITION AND THE ECONOMIC TRANSFORMATION OF THE SILESIAN VOIVODESHIP

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Purpose: The article discusses the results of the SWOT analysis, which concerns the results of research conducted by the Central Mining Institute (GIG-PIB) and the Miners' Union of the Republic of Poland (ZZG), and relating to the transformation process[1].
Methodology: The SWOT analysis was based on the results of qualitative and quantitative research conducted as part of the project by GIG-PIB and ZZG. The qualitative research tools were: desk research, group interviews and in-depth interviews.
Findings: the research indicates that one of the key elements supporting the transformation process is investing in education and training. This research also shows that it is to provide financial support and social dialogue, which enables the involvement of various stakeholders in the transformation process.
Research limitations/implications: t he scope of data used in the SWOT analysis may not include all identifiable strengths and weaknesses of the Silesian Voivodship, but only those that appeared in the responses of the respondents to the aforementioned study.
Practical implications: the SWOT analysis indicates that in the case of transformation, there is a need for a long-term, planned transition to a new model of economic development. However, the level of preparedness of enterprises, especially those related to mining, is still too low, especially from a financial perspective.
Social implications: in the social dimension, the main problem in the transformation is the threat resulting from the possibility of losing jobs n and the related possibility of increasing unemployment and social exclusion in the region.
Originality: the economic transformation of the Silesian Voivodship is a huge challenge, but also an opportunity for the development and modernization of the region. The SWOT analysis identifies key strengths and weaknesses, opportunities and threats related to the

[1] This article presents the results of the qualitative research conducted by the Central Mining Institute – National Research Institute as an input to the Regional Observatory of the Transformation Process (ROPT) project, co-financed by the European Union through the Just Transition Fund.

decarbonization process. Social research emphasizes the need to invest in education, retraining and social dialogue in order to ensure a fair and effective transformation.
Keywords: just transition, coal dependent region, coal phase-out, economic changes.
Category of the paper: research paper.

1. Introduction

The concept of Just Transition is closely related to the long-term process of decarbonization and moving away from coal, which is the basis of the European Union's climate policy. The concept of a Just Transition has gained significant traction in recent years, especially within the European Union as it strives to address climate change and shift towards sustainable development.

The impulse to think about a just and energy transition is the environmental pressure that has been growing for decades, expressed in international declarations and political documents related to, among others, the 2030 Agenda (United Nations, 2015) the Paris Agreements (United Nations Climate Change, 2015) or the European Green Deal. The European Green Deal, adopted in 2019 (European Commission, 2019), incorporates the Just Transition Mechanism, which aims to provide financial support and technical assistance to regions heavily dependent on fossil fuels. The mechanism is designed to mitigate the social and economic impacts of the transition toward the declaration "…no one left behind" (Timmermans, 2021).

The concept of a Just Transition is crucial for ensuring that the shift towards a low-carbon economy is equitable and inclusive. The United Nations Framework Convention on Climate Change has consistently emphasized the importance of Just Transition in its annual climate conferences (COPs). The 2018 "Solidarity and Just Transition Silesia Declaration" adopted at COP24 in Katowice, Poland, called for a transition that respects the rights of workers and promotes social justice (UNFCCC, 2018).

As countries and regions worldwide adopt policies to tackle climate change, it is essential to incorporate Just Transition principles to protect workers and communities affected by these changes. Literature and case studies highlight the importance of economic diversification and social dialogue, (Kapetaki, Ruiz, 2020; Kimimbi, 2023), skills development (European Commission, 2020; Promea, 2021; Bianchi et al., 2022), social protection, and environmental sustainability in achieving a Just Transition (Fankhauser et al., 2008; Caldecott, 2017; Stanley et al., 2018; Casano, 2019). By prioritizing these principles, policymakers can help ensure that the benefits of the green economy are shared broadly, fostering a more just and sustainable future (Nowakowska et al., 2021). Within the EU context, a Just Transition encompasses both the creation of decent work opportunities and the protection of workers' rights, particularly those in industries directly affected by decarbonization efforts (ILO, 2015; ETUI, 2020).

A Just Transition involves several key principles, one of them being economic diversification and resilience, supported by promoting economic policies that foster diversification and resilience in affected regions and create new opportunities for sustainable employment. A just transition should also refer to the creation of new development pathways in coal regions or in areas dependent on traditional industries. From this perspective, far-reaching structural reform is needed if these places are to continue to act as growth hubs (Drobniak, 2022).

Closing mines is a process that always arouses a lot of emotions and controversy. On the one hand, it aims environmental protection, but on the other hand, it can lead to serious economic and social consequences. The Just Transition of the mining industry is a process of change aimed at reducing the negative effects of the extraction of raw materials on the environment and human health, but introducing changes always carries certain risks. They may be particularly important in areas such as the outflow of employees from the region, decrease in the income of mining-related enterprises, decrease in the income of residents and deepening of areas of social exclusion. However, a change in industrial structure can also open up new growth opportunities and stimulate investment in new technologies, such as renewable energy or digital technologies, which can attract investors and create new jobs.

2. Regional context of the Silesian Voivodship

Poland, as EU member states aim to reduce carbon emissions and adopt greener practices, the principle of a Just Transition emphasizes the importance of ensuring that these changes are equitable and inclusive, protecting the livelihoods of workers and communities affected by the transition. Poland's Silesian region, heavily dependent on coal mining, has been a focal point for EU Just Transition funding. The region has received significant support to develop renewable energy projects, retraining programs, and economic diversification initiatives (European Commission, 2020). Toward the long-term goal of climate neutrality adopted by the European Union by 2050, the Silesian Voivodship is facing a huge challenge to carry out a just transition that will require changes at the social, economic and environmental levels (Ślimko, 2019).

The Silesian Voivodship is located in the southern part of Poland and is in second place in terms of the number of inhabitants. The region is inhabited by 4346.7 thousand inhabitants, which is 11.5% of the country's population. The Silesian Voivodship is the most industrialized region in Poland and one of the most industrialized areas in Europe. It is characterized by the largest employment in the country, which amounts to 11.5 per cent of the national employment in the national economy. The value of the GDP of the Silesian Voivodship is PLN 313,592 million, which means that the Silesian Voivodship ranks 4th in terms of the amount of PK

per 1 inhabitant. The economy of the province is dominated by the following industries: coal in Silesian mines producing 90.2% of the sold production of hard coal mining in Poland) and metallurgy, as well as the electromechanical, metal, chemical and food industries (GUS, 2023).

The Silesian Voivodship is also the most coal-dependent region in the European Union. 22 of 25 operating coal mines are placed here. Since the beginning of the 90s of the twentieth century, coal production in Poland has decreased by half (from almost 150 million tons to about 73 million tons), and employment in the mining sector has decreased fourfold) between 1990 and 2015 from about 388 thousand to about 98 thousand), but the Silesian Voivodship is still recorded by the largest number of employees in the mining industry (Terytorialny Plan…, 2022). The number of mining-related enterprises varies depending on the sources from about 370 to over 900, and they create from 110 to 130 thousand stable jobs (Górnicza Chamber…, 2020). It is estimated that as a result of the green transformation, about 36 thousand jobs will be lost in the mining and mining-related sectors in the Silesian Voivodship by 2030. In total, in this process, the scale of job losses will affect about 145 thousand people. The economic transformation of the Silesian Voivodship is in line with the assumptions of the Territorial Just Transition Plan of the Silesian Voivodship 2030 (TPST 2022) and other regional strategies, such as the Development Strategy of the Silesian Voivodship "Śląskie 2030 - Zielone Śląskie" (Marshal's Office of the Silesian…, 2020). The Territorial Just Transition Plan of the Silesian Voivodship 2030 is a key operational action plan in the area of transformation. The Plan emphasizes the need to change the generation structure and develop the energy sector in the region, as well as supporting the labor market. Mitigating the social, economic and environmental impacts of the transition towards climate neutrality is the most important objective of the Plan. The implementation of the Plan TPST provisions are to be ensured by a dedicated source of financing included in the European Funds for Silesia 2021-2027 and other sources of financing.

Despite the detailed framework provided by the Territorial Just Transition Plan (TPST 2030) and access to resources such as the Just Transition Fund, implementation progress has been uneven. Local actors have raised concerns about bureaucratic delays, insufficient coordination between local and national levels and the under-utilisation of allocated EU funds. Monitoring reports also indicate that while planning is advanced, the actual disbursement of investments and support measures on the ground lag behind. These observations suggest a gap between political ambition and the capacity to deliver, which requires improved governance mechanisms and stakeholder alignment. A comparative perspective of EU coal regions

Compared to other EU coal regions in transition – such as North Rhine-Westphalia in Germany or Western Macedonia in Greece – the Silesian Voivodeship shows both strengths and areas lagging behind. Unlike Germany, which has built strong innovation ecosystems and early investments in renewable energy, Silesia still demonstrates a strong economic dependence on mining. However, the region benefits from a stronger industrial infrastructure than some other regions, offering latent transformation opportunities. Lessons from more advanced

transformations in Germany and Spain suggest the need for earlier diversification strategies, more active engagement of SMEs and stronger regional innovation policies.

3. Methodology

In 2022-2023, the Marshal's Office of the Silesian Voivodship together with its partners: the Central Mining Institute – National Research Institute (GIG-PIB), the Mining Chamber of Industry and Commerce and the Trade Union of Miners in Poland (ZZG) implemented a project entitled the Regional Observatory of the Transformation Process (ROPT), co-financed by the European Union under the European Regional Development Fund. As part of the project, GIG-NRI developed a Strategic Balance for the priorities of just transition in the Silesian Voivodship, which is a summary of the results of social research by GIG-NRI and ZZG. The research concerned 8 thematic areas:

I. Research areas carried out by the ZZG:

1. Expectations of employees of mines and mining-related companies regarding the outplacement offer in connection with the planned decarbonization.
2. Vision and plans of the main stakeholders in the face of the challenges of decarbonization of the region.
3. The role of trade union leaders in the process of changes determined by the transformation of the Polish mining industry.
4. Attitudes of employees of mines and mining-related companies towards changes in their activity and professional career.

II. Research areas carried out by GIG-NRI:

5. Anticipating future skills and the intrinsic potential of entrepreneurs.
6. The impact of the closure of coal mines on the local environment, entrepreneurs, the labor market, among others.
7. Involving stakeholders in social dialogue in the process of closing a mining plant to reduce the possibility of social conflicts.
8. Predicting and mitigating the possibility of negative social effects related to the process of mine closures and protecting employees from dismissal.

The research carried out as part of the ROPT project covered the following groups of stakeholders in the transformation process: employees of mining and mining-related plants, entrepreneurs and employers, leaders of trade unions in the mining sector, representatives of local governments and their organizational units, representatives of employers' organizations, employees, economic self-governments, business environment institutions and representatives of non-governmental organizations. The tool used to develop the Strategic Balance was a SWOT analysis in three areas: economic, social and environmental, in line with the TPST areas.

The SWOT methodology, which stands for Strengths, Weaknesses, Opportunities and Threats, is a strategic planning tool used to identify and analyze the internal and external factors that can impact the success of a project, organization, or business venture (Minsky, Aron, 2021). The SWOT analysis is distinguished primarily by its versatility and simplicity, which helps in the assessment of the analyzed factors and allows for a more complete understanding of its situation in the environment, in this case in the socio-economic environment. Therefore, SWOT analysis is very often the basis for the strategic planning process and is a valuable tool that allows you to better understand the environment and make informed strategic decisions (David, 2011; Tomski, 2017).

This article discusses the results of the SWOT analysis, which concerns the results of research carried out by the Central Mining Institute and ZZG and relating to the area of economy. The SWOT analysis was based on the results of qualitative and quantitative research carried out as part of the project by the GIG-PIB and the Trade Union of Miners in Poland. Qualitative research tools included: desk research analyses, focus group interviews (FGI) and in-depth interviews (IDI). Qualitative research was carried out in the form of quantitative research (CAWI). The scope of data that was used in the SWOT analysis may not take into account all identifiable strengths and weaknesses of the Silesian Voivodship, but only those that appeared in the responses of the respondents to the above-mentioned survey.

4. SWOT analysis

Research conducted by GIG and ZZG indicates that one of the key elements supporting the economic transformation process is investment in education and training, which enable the retraining of coal sector employees for new professions, especially in new, developing sectors such as the green economy. These studies also show that it is to provide financial support and social dialogue important that allows the involvement of various stakeholders in the process of economic transformation of the region. Table 1 presents the SWOT analysis of the Silesian Voivodship, based on the results of the ROPT project, about economic transformation (Jarosławska-Sobór et al., 2023).

Table 1.
SWOT analysis

Strengths	**Weaknesses**
A lower sense of risk of losing their jobs by employees of mining companies due to the adopted social contract for hard coal mining. Acceptance of the process of diversification of business activity and no fear of entrepreneurs in the non-mining industry related to the need to reorganize the company and change its business profile.	Poor financial condition of some enterprises, especially mining-related ones. Insufficient financial support for small businesses. Lack of alternative high-quality jobs (level of salaries, benefits, durability of employment, social prestige) in the mining sector.

A large number of enterprises in the region. Locating large, well-known companies in the region, generates new jobs and increases the level of competitiveness. There is a high demand for construction companies that can take over employees of mining plants. Qualified staff (workers, management) in the Silesian Voivodship. Good transport infrastructure strengthens the mobility of workers and creates an incentive effect for investors. Knowledge and experience of instruments motivating and demotivating employees to take up employment from the period of restructuring of the mining sector in the 1990s. Financial support and development programs in the field of transformation for entrepreneurs and employees. Taking actions in mining-related companies aimed at mitigating the negative effects of the transformation in the form of rebranding operations and improving the competencies of employees. Increase in innovation of non-mining companies. Development of the ecological services sector. The ability to work in difficult conditions is characteristic of employees of mining and mining-related companies. Loyalty and commitment of employees in the mining sector, the Silesian work ethos. Low number of unemployed in the Silesian Voivodship. Improving the image of companies and the region related to the energy transition. Access to global markets for entrepreneurs in the Silesian Voivodship, resulting from the development of technology. Increased social awareness of customers/consumers and increased demand for green services and technologies ~~which~~ are the driving forces behind companies' innovation. Innovation and research as new opportunities for the development of entrepreneurship.	Instability of working conditions and wages, especially in private companies. The problem with the recruitment of qualified employees is a significant limitation for the development of non-mining enterprises. A decrease in the revenues of local governments of mining municipalities and impoverishment of mining regions, resulting in lower quality of social services and an adverse impact on local communities. Poor entrepreneurial activity of the inhabitants of mining regions. Lack of prepared investment areas. Financial and administrative difficulties in the implementation of projects related to renewable energy sources. The complexity of the energy and socio-economic transformation process requires multidirectional actions. Time-consuming activities spread over decades of the energy transition process. High costs of energy and socio-economic transition causing an economic slowdown. A high degree of dependence of mining-related companies on mines due to the focus on providing services to coal mines which is a serious obstacle to the possibility of changing the business profile.

Acceleration of technological progress in the Silesian Voivodship, related, among others, to the adoption of the Development Strategy of the Silesian Voivodship "Śląskie 2030". Green Silesia.	
Opportunities	**Threats**
Greater involvement of entrepreneurs in the transformation process as entities that know the local market best. A high degree of involvement of the regional government in providing support for transformation projects is recognized by mutual trust and direct contact. Support for non-mining entrepreneurs in the form of financial instruments intended for changing the business profile, introducing new technology, and refinancing the employment of employees. Non-financial support to train workers and stimulating the market through public works procurement. Development of vocational and vocational education addressed to both young people and adults. Re-skilling programs and professional development support. Energy efficiency and energy efficiency, meaning the development of the renewable energy sector. The development of new sectors of the economy brings new markets and export opportunities. Innovative technologies and solutions that affect the development of entrepreneurship in society. Financial support and subsidies for entrepreneurs. Investments in infrastructure, including post-mining infrastructure.	A need for long-term planning of adaptation measures, even before the final closure of the mining plant. Problems related to finding alternatives to mining, especially in the context of creating new jobs and retraining employees. Increase in the number of unemployed people. Concerns about the future of the workplace that demotivate and reduce productivity. There is no system of institutional assistance at the government level, addressed to mining-related companies. Regulations on granting state aid limit the possibilities of aid addressed to mining-related companies. Low involvement, results from the lack of an incentive system and a low sense of the need for entrepreneurs to be involved in the transformation process. The problem with maintaining the level of salaries of employees moving from large mining and mining-related companies to the SME sector. Lack of availability of energy at prices whose level will not adversely affect the possibility of development and competitiveness of the Polish economy. High financial and social costs of the green transition. The collapse of companies dependent on mining. Decrease in tax revenues in mining municipalities. Uncertainty related to political decisions and legal regulations. Social and political resistance to transformational changes.

Source: GIG-PIB own research.

In summary, the SWOT analysis provides a comprehensive understanding of the internal opportunities and external conditions shaping the economic transformation of the Silesian Voivodeship. The combination of a strong industrial infrastructure, a strong workforce and EU financial mechanisms creates a unique opportunity for growth. However, challenges such as over-reliance on coal and social resistance to change require coordinated strategies and

targeted investments. These results underline the critical role of proactive planning, education and stakeholder engagement in ensuring a successful and just transition.

5. Key conclusions and recommendations resulting from the SWOT analysis

Research conducted by GIG and ZZG indicates that one of the key elements supporting the economic transformation process is investing in education and training, which enable the retraining of coal sector employees for new professions in the green economy sector. These studies also show that it is important to provide financial support and social dialogue, which enables the involvement of various stakeholders in the transformation process. The SWOT analysis indicates that in the case of the transformation of mining regions, there is a need for a long-term, planned transition to a new model of economic development. However, the degree of preparation of enterprises, especially those related to mining, is still too low, especially from a financial perspective. The analysis of the degree of preparation of key staff to carry out restructuring processes is also insufficient. The key conclusions resulting from the SWOT analysis are presented below.

6. Conclusions

1. Key strengths are:
    - Well-developed industrial infrastructure. The Silesian Voivodship has a well-developed industrial infrastructure, which provides a solid basis for businesses transforming into greener enterprises.
    - Skilled workforce. The region has a highly skilled workforce, particularly in the mining and industrial sectors, which enables the retraining of workers for new green economy professions.
    - Financial support from the European Union: Access to EU funds, such as the Just Transition Fund, supports coal regions in the transition process, enabling the financing of investments in new technologies and sectors of the economy.
2. Key weaknesses are:
    - Strong dependence on the coal industry. The economy of the Silesian Voivodship is heavily dependent on the coal industry, which hinders a quick and effective transition.

- Social and economic problems. The closure of mines and mining-related companies carries the risk of increased unemployment and social exclusion, which may lead to economic destabilization of the region.
- Insufficient infrastructure for new sectors. Existing infrastructure is not fully adapted to the needs of new technologies and low-emission economy sectors, requiring additional investment.

3. Key opportunities are:
   - Development of the renewable energy sector. Investments in renewable energy, such as wind, solar or geothermal, can create new jobs and reduce greenhouse gas emissions.
   - Increase in innovation. Promoting technological innovation and supporting research and development can contribute to the diversification of the region's economy and increase its competitiveness in the international market.
   - Education and training programs. Introduction of education and training programs enabling the retraining of employees from the coal sector for new professions in the green economy sector.
4. Key threats are:
   - Social resistance to change. Social opposition to the closure of mines and the transformation of the economy may slow down the transformation process and increase social tensions.
   - Potential economic losses. The closure of the coal industry may lead to significant economic losses and difficulties in attracting new investments.
   - Lack of a coherent support policy. Insufficient policy support and a lack of a long-term strategy can lead to inefficiencies and delays in achieving the transformation goals.

The proposed recommendations highlight the basic strategies for implementing a just transition in Silesia. They emphasize the importance of aligning education, innovation, infrastructure and policy to mitigate the socio-economic risks associated with coal phase-out. These guidelines aim to support regional authorities, policymakers, trade unions and business leaders in organizing a coherent and resilient transition framework.

7. Recommendations

Based on the SWOT analysis and the conclusions drawn from it, key recommendations for supporting the Just Transition process have been developed, which are presented in table 2.

Table 2.
SWOT analysis recommendations

	Recommendation	Characteristic
1.	Increasing investment in education and training.	Extensive training programs need to be put in place to enable coal workers to be retrained for new jobs in the green economy. Education and training are key to ensuring the competitiveness of the region's economy and reducing the risk of unemployment and social exclusion.
2.	Long-term planning of adaptation activities.	It is necessary to carry out such activities even before the final closure of the mining plant. The plans should concern specific actions, primarily in the areas of employment requalification and change in the use of infrastructure and mining land located in a given mining municipality, taking into account social participation, along with determining the possibility of financing the necessary changes.
3.	Development of infrastructure supporting new technologies.	Investments in technological and industrial infrastructure are essential to attract new investments and support the development of innovative sectors of the economy. Modernization of existing infrastructure and the construction of new technological facilities can contribute to the creation of new jobs and increase the competitiveness of the region.
4.	Promoting renewable energy.	Investments in renewable energy sources, such as wind, solar and geothermal, can help reduce greenhouse gas emissions and create new jobs in the green economy. Promoting renewable energy can also increase the region's energy security and reduce its dependence on fossil fuels.
5.	Fostering technological innovation.	Promoting technological innovation and supporting research and development are key to diversifying the region's economy and increasing its competitiveness. Investments in new technologies and support for entrepreneurship can contribute to the creation of new jobs and increase the attractiveness of the region for investors. It is important to increase the attractiveness of the Silesian Voivodship for investors who may be interested in the development of new technologies and industries in the region.
6.	Activation of entrepreneurs.	Tools should be introduced that would involve entrepreneurs to a greater extent and a strong emphasis should be placed on showing the opportunities offered by the transformation process. An example may be the creation of banks of ideas and new development opportunities for transformed areas, such as investing in new sectors and industries, in infrastructure, in the creation of new jobs, the use of local resources, including with the participation of local communities.
7.	Providing financial and political support.	Government must provide coherent and long-term financial and policy support for the economic transition process. This support should include funds for investment in new technologies and education and training programs, as well as actions to foster social dialogue and partnerships between different stakeholders.
8.	Silver economy as a trigger for new economy.	The developing and increasingly important "silver economy" can be one of the alternatives to employing workers from declining sectors and at the same time an impulse for development in transformation.

Source: GIG-PIB own research.

8. Summary

Decarbonization energy transition involves a transition from an economy based on traditional fossil fuels to a sustainable, low-carbon and circular economy. Striving for a green transition of coal regions is an opportunity to build a more sustainable future. The key to success will be to coordinate efforts at all levels, from international organizations to national governments to local communities. Only then will it be possible to achieve the goals of Just Transition, environmental protection and creating better prospects for future generations.

One of the most important elements of Just Transition is the need to protect employees at risk of losing their jobs, but also the need to create an alternative development alternative for coal-dependent companies, for which the changes pose a threat of collapse and liquidation. Just transition is also an opportunity for the regions. The implemented just transition mechanisms are aimed at supporting activities for investments in renewable energy sources and the creation of new markets related to the green economy or sustainable transport.

The economic transformation of the Silesian Voivodship is a huge challenge, but also an opportunity for the development and modernization of the region. A SWOT analysis identifies key strengths, weaknesses, opportunities and threats related to the decarbonization process. Social research highlights the need to invest in education, retraining and social dialogue to ensure a just and effective transition.

The conducted research and analyzes show that in the aspect of planning and conducting transformation in the Silesian Voivodship, the priority should be to use the potential of the region itself, i.e. human capital and its qualifications, innovations, implementation of green energy, the potential of post-industrial areas and the development of tourist services using local environmental resources. It is necessary to develop new industries and enterprises that could use the resources and capabilities of the Silesian Voivodship, such as the chemical industry or tourism. This development is of great importance for stimulating the region's economy and increasing attractiveness for investors and thus will have an impact on improving competitiveness.

In the social dimension, the main issue is the threat resulting from the possibility of losing a job in connection with the liquidation of mines and mining-related companies and the related possibility of an increase in unemployment and social exclusion in the region. Transformation is a long-term process for which it is necessary to prepare and plan its course even before the final closure of the mining plant. It is necessary to support employees and local communities dependent on the mining industry by creating new jobs, eg in the sectors of renewable energy sources, energy efficiency and new technologies, employment in new positions (redeployment, re-skilling) or the use of effective social support instruments.

Importantly, the successful economic transformation of the Silesian Voivodeship can become a model for other coal regions worldwide, showing that decarbonization and regional development are not mutually exclusive. To fully leverage the lessons learned from this research, practical steps should include resource mobilisation through cross-sector partnerships, regional incentive schemes and targeted training programmes for future-proof professions. The findings presented here will support policymakers designing transition strategies, institutions managing EU and national funds, local governments driving structural reforms and businesses exploring opportunities in green growth sectors. SMEs and stronger regional innovation policies.

References

1. Bianchi, G., Pisiotis, U., Cabrera Giraldez, M. (2022). *GreenComp The European Sustainability competence framework.* Punie, Y., Bacigalupo, M. (eds.), EUR 30955, Luxembourg: Publications Office of the European Union.
2. Caldecott, B., Sartor, O., Spencer, Th. (2017). *Lessons from previous " coal transitions " - High Level Summary for Decision-Makers.* Institute for Sustainable Development and International Relations (IDDRI), Climate strategies. https://apo.org.au/node/97371
3. Casano, L. (2019). Skills and Professions for a "Just Transition ". Someone Reflections for Legal Research. *E-Journal of International and Comparative Labor Studies, 8(3),* 31-46.
4. Central Statistical Office (2023). *Report on the socio-economic situation of Silesian Voivodeship 2023.* Katowice.
5. David, F.R. (2011). *Strategic Management: Concepts and Cases* (13th ed.). Prentice Hall.
6. Drobniak, A.(ed.) (2022). *Just transformation of coal regions in Poland. Impulses, contexts, strategic recommendations*. Katowice: University of Economics Publishing House.
7. European Commission (2019). *The European Green Deal.* COM 2019/640. Brussels.
8. European Commission (2020). *Europe 2020 Flagship Initiative "An agenda for new skills and jobs".* https://energy.ec.europa.eu/topics/research-and-technology/strategic-energy-technology-plan_en
9. European Commission (2020). *Just Transition Fund: Supporting the regions most affected by the transition towards the green economy*. https://www.europarl.europa.eu/factsheets/en/sheet/214/just-transition-fund
10. European Trade Union Institute (2020). *Towards a Just Transition: Coal, Cars and the World of Work.* Brusselss: ETUI.
11. Fankhauser, S., Sehlleier, F., Stern, N. (2008). Climate change, innovation and jobs. *Climate Policy, 8(4),* 421-429.
12. GIPH (2020). *The situation of mining-related enterprises in Poland*. Katowice.
13. International Labor Organization (2015). *Guidelines for just transition towards environmentally Sustainable economies and societies for all*.
14. Jarosławska-Sobór, S. (ed.), Hetmańczyk, P., Koteras, A., Kruczek, M., Marszowski, R., Pilch, A., Uszok, E. (2023). *Strategic Balance for the priorities of a just transformation for the Silesian Voivodeship.* Katowice: GIG-PIB.
15. Kapetaki, Z., Ruiz, P. et al. (2020). *Clean energy technologies in coal regions: Opportunities for jobs and growth: Deployment potential and impacts*. Kapetaki, Z. (ed.). EUR 29895 EN. Luxembourg: Publications Office of the European Union.
16. Kimimbi, F. (2023). *Green Competences for trade unionists: a case-based approach*. Brussels: European Trade Union Institute.

17. Marshal's Office of the Silesian Voivodship (2020). *Development Strategy of the Silesian Voivodship "Śląskie 2030" - Green Silesia, adopted by the resolution of the Silesian Regional Assembly No. VI/24/1/2020 of October 19, 2020*.
18. Minsky, L., Aron, D. (2021). Are you doing the SWOT analysis backwards? *Harvard Business Review*.
19. Nowakowska, A., Rzeńca, A. Sobol, A. (2021). Place- Based Policy in the "Just Transition" Process: The Case of Poland Coal Regions. *Land, 10,* 1072. https://doi.org/10.3390/
20. PROMEA (2021). *RES-SKILL Project Report 02-T1: Skills matching analysis and development of transition profiles*. https://res-skill.eu/
21. Ślimko, E. (2019). *Just Transition of Silesia. Challenges from the civil society perspective - analysis and recommendations*. Warsaw: Alliance of Associations Polish Green Network.
22. Stanley, M.C., Strongman, J.E., Perks, R.B., Nguyen, H.B.T., Cunningham, W., Schmillen, A.D., McCormick, M.S. (2018). *Managing Coal Mine Closure: Achieving a Just Transition for All* (No. 130659). The World Bank.
23. Timmermans, F. (2021). *The Just Transition Mechanism: making there is no one for sure left behind,* https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/finance-and-green-deal/just-transition-mechanism
24. Tomski, M. (2017). *SWOT Analysis: Idea, Methodology and a Practical Approach*. GRIN Verlag.
25. TPST (2022). *Territorial Just Transition Plan for the Silesians Voivodship 2030. Katowice 2021, adopted by the Resolution of the Management Board of the Silesian Voivodeship No. 2326/383/VI/2022 of 21 December 2022*.
26. United Nations (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development*, https://sdgs.un.org/2030agenda
27. United Nations Climate Change (2015). *Paris Agreement*.
28. United Nations Framework Convention on Climate Change, UNFCCC (2018). *Solidarity and Just Transition Silesia Declaration*. https://unfccc.int/sites/default/files/resource/Inputs%20from%20India%20Water%20Foundation.pdf

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CLIMATE CHANGE RELATED TRANSPORTATION MANAGEMENT IN PAKISTAN – GREENHOUSE GAS EMISSION REVIEW, MITIGATION STRATEGIES AND ADAPTATION MEASURES

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Purpose: Greenhouse gas emissions in Pakistan are primarily caused by the growing transportation sector, due to urbanization, population growth, and the country's heavy reliance on fossil fuels. The paper examines existing greenhouse gas emissions in Pakistan's transport sector, evaluates the present response strategies, and explores how Pakistan can adapt to climate change.
Methodology: The article uses an analytical approach, based on a literature review. The approach taken is guided by the PRISMA framework and groups results from over 115 relevant articles and official reports. This paper presents how electric vehicles, alternative fuels such as compressed natural gas (CNG), and sustainable public transport help cut emissions.
Findings: Findings show that working on all three aspects of technological development, policy changes, and infrastructure projects is necessary for reaching sustainable and resilient transportation in Pakistan.
Research limitations and implications: The study was cross-sectional and covered a selected group of respondents, which may influence the generalization of the results. In the future, it would be beneficial to expand the analysis to include data from different markets and to study the long-term effects of implementing innovations in distribution logistics.
Practical implications: The presented analysis is based on secondary materials, it outlines needed research and explains how its conclusions can be used in national policy and city management.
Social implications: The final part of the paper includes policy recommendations and outlines where future research could be focused.

Originality/Value: The article contributes to the literature on greenhouse gas emissions in Pakistan by presenting current trends and challenges.
Keywords: Greenhouse gas emissions, transportation climate change, strategies to lessen emissions, options for adapting to climate change, sustainable development.

1. Introduction

The changes in climate are mostly caused by humans burning fossil fuels, cutting down forests, using certain industrial processes, and making cities bigger (Landsberg, 1970). This has taken place much quicker than usual because of the giant rise in GHGs in the air, mainly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (NO_x) (Solomon et al., 2009). Increased GHG emissions are responsible for global warming, unpredictable weather, and the occurrence of extreme weather situations such as heavy rains, storms, and heat waves (Walsh et al., 2016).

According to NOAA, the average temperature on Earth has increased by about 1°C over the last century, mainly due to people influence on the climate in recent decades (Wuebbles et al., 2017).

Most of the increase in global temperatures can be explained by how much CO_2 is released into the air by burning coal, oil, and natural gas for producing and transporting energy (Age & Anomaly, 2008). As the (Figure 1) demonstrates, all datasets show global temperatures rising consistently since the pre-industrial period, starting around 1880 (Hansen et al., 2010).

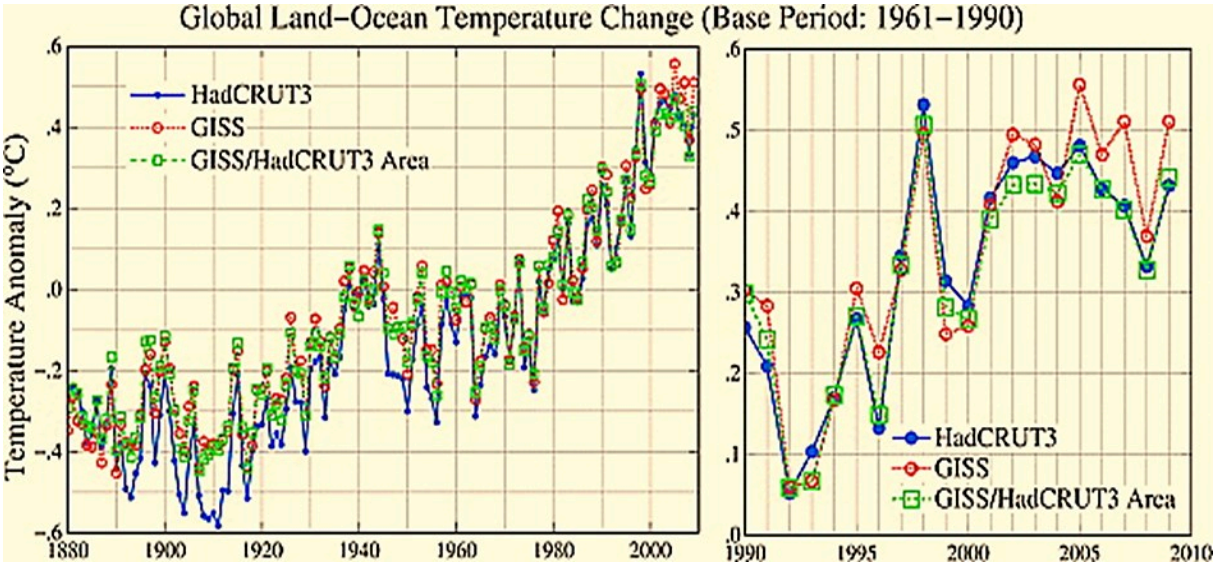

Figure 1. Global surface temperature anomalies (°C) relative to the 1961-1990 base period for three cases: HadCRUT3, GISS, and GISS anomalies limited to the HadCRUT area.

Source: (Hansen et al., 2010).

The transportation industry is responsible for 16% of worldwide greenhouse gas (GHG) emissions, as evident in (Figure 2). When it comes to transportation, no other method accounts for more emissions than road transport, with 12% of the total. After that, aviation and maritime

transport add 1% and 2% respectively (Alfredo Rivera, November 26, 2024). The reliance of the transport sector on gasoline, diesel, and jet fuel is the primary reason it significantly contributes to global climate change (Yaoxian Huang 2020). Based on (Figure 2), the transportation sector causes a lot of emissions, which contribute to global warming and worsen the global climate crisis.

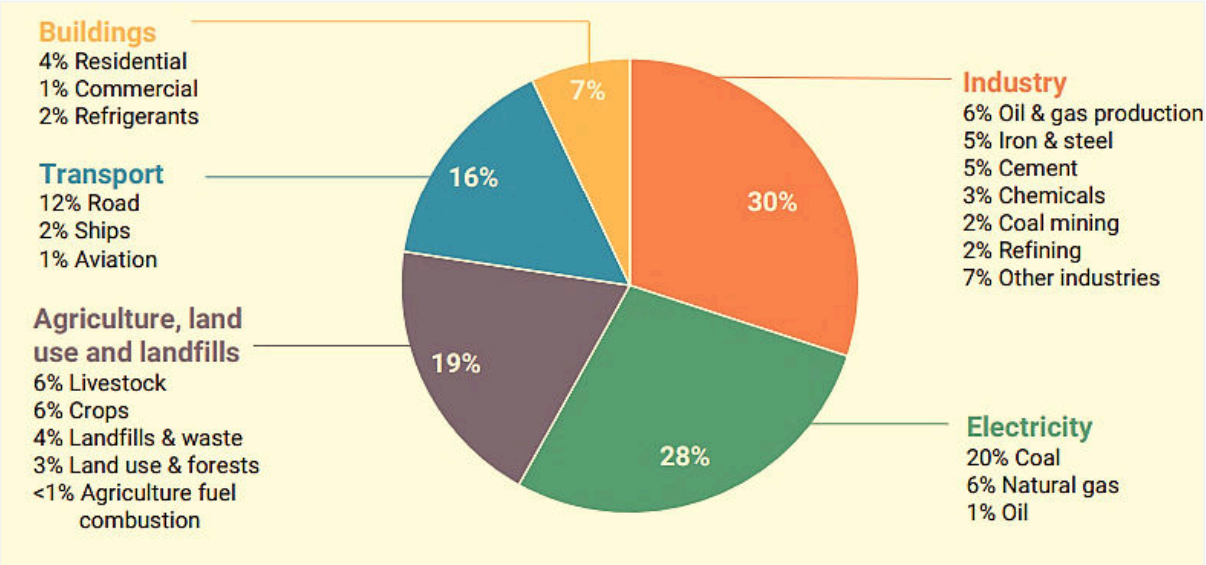

Figure 2. Global Emissions of GHG by Sector.

Source: (Alfredo Rivera, November 26, 2024).

Since transportation causes a lot of emissions, reducing them is crucial to achieving the global climate targets agreed by countries, such as in the Paris Agreement, which aims to limit global warming to well below 2°C above pre-industrial levels (OECD/ITF, 2018; UNFCCC, 2015). While North America, Europe, and East Asia have advanced by using cleaner technologies and making laws to reduce emissions from transport, many underdeveloped countries, including Pakistan, experience difficulties with this challenge. Because of swifter city growth, more factories, poor infrastructure, and a rise in personal cars, transportation is having a bigger negative effect on the environment in developing areas (Partnership, 2021; Transport, 2023).

As people in Pakistan and other countries continue to live in the city, pollutants from road vehicles are likely to rise sharply unless action is taken (Partnership, 2021). As cities are growing fast and new vehicles keep being produced, road transport is becoming responsible for an increasing amount of greenhouse gas emissions (change, 2022; IEA, 2023). The rising use of road vehicles, as illustrated in (Figure 2), makes it important to implement useful methods for reducing emissions (Sims, 2014). While energy production accounts for one-fourth of worldwide CO_2 emissions, it is clear that road transport plays the biggest role (Creutzig, 2015; IEA, 2023).

In cities, mainly in growing countries, busy highways and poor public transport lead to higher emissions and can harm both nature and health (Anenberg et al., 2017; WHO, 2018). If EVs, alternative fuels, and green public transport are not widely used, the harmful emissions from vehicles will keep increasing, leading to more global climate change (IEA, 2023). Therefore, decreasing emissions from road traffic is necessary to contribute to worldwide climate action and to address conditions caused by climate change (Change, 2022).

Climate change is affecting people all around the world and is causing many challenges in economic and social areas (Change, 2022; Stern, 2008). Regions near the coast are being affected by higher sea levels, and dry regions are experiencing longer problems with droughts (Dai, 2013; Nicholls et al., 1999). When rainfall patterns are unstable, many crops fail to grow as much as expected, leading to less food for people (Lobell et al., 2011; Wheeler, Von Braun, 2013). Moreover, heatwaves, large storms, and floods are happening more often, endangering people, buildings, and businesses (Emanuel, 2017). As shown in (Figure 3), various climate change effects, notably extreme weather and unstable precipitation, directly endanger the global food security and nutrition systems (Farooq et al., 2022).

Such disruptions often lead to reduced harvests, problems with getting food to markets, and an increase in malnutrition among people in South Asia. Therefore, it is very important to cut emissions from energy, agriculture, and transportation to deal with climate change and support the stability and sustainability of global systems (FAO, 2018).

Compared to other sectors, the transportation sector in Pakistan is responsible for releasing the most greenhouse gases. Rapid growth in urbanization, industry, and population has caused the sector's share of $C0_2$ emissions in the country to go up year by year. According to reports from UNFCCC and the World Bank, more than 20% of all greenhouse gas emissions in Pakistan come from the transport industry (Imran, 2010; Observatory, 2023).

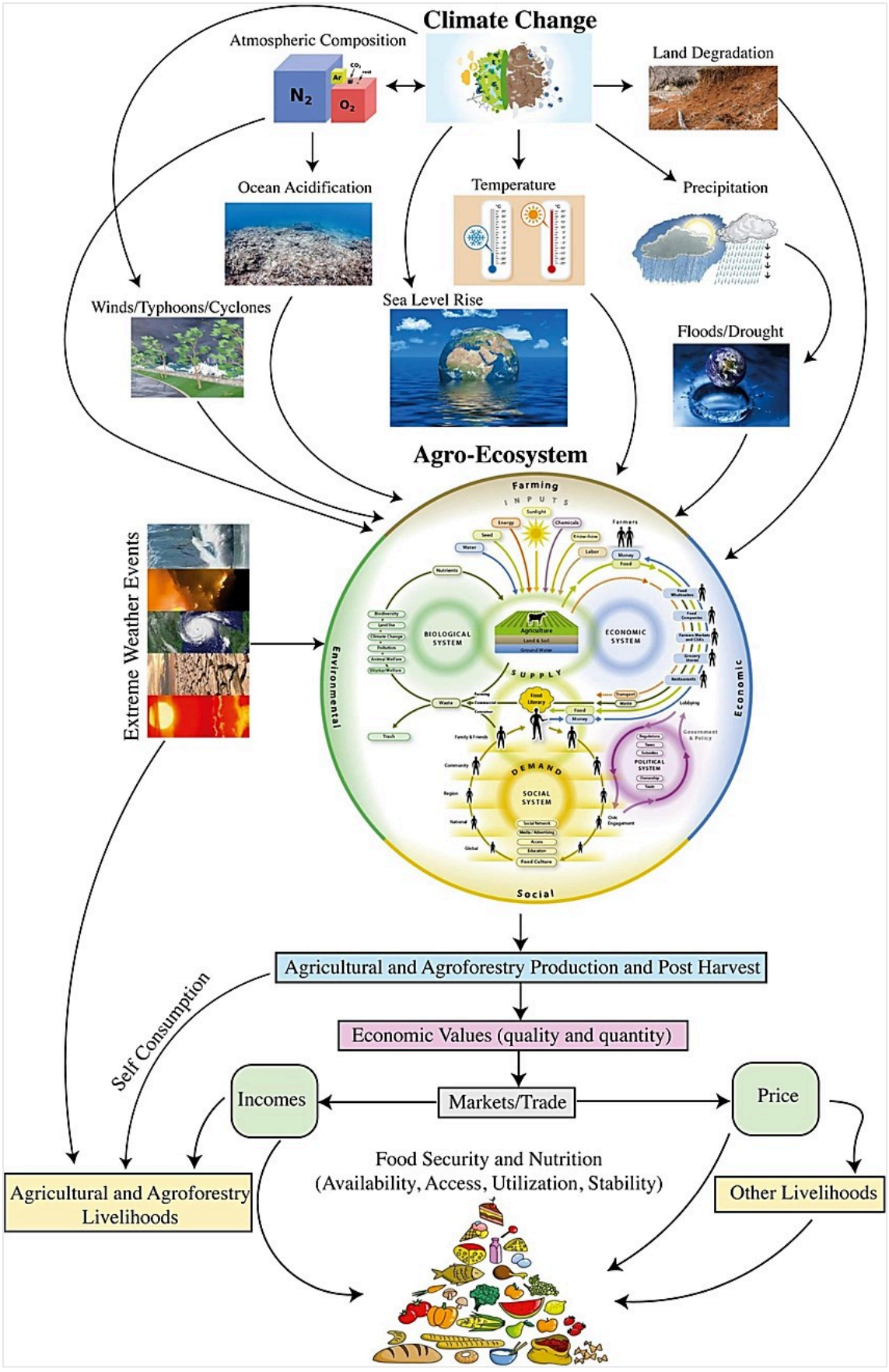

Figure 3. Schematic representation of climate change impacts on global food security and nutrition. Source: (Farooq et al., 2022).

The transportation that generates the most of these emissions is mainly from passenger vehicles, freight trucks, and motorcycles (Analytics, 2024; Kumar et al., 2024). While Karachi, Lahore, and Islamabad are experiencing more people owning vehicles, this is leading to increased emissions and more air pollution (Kumar et al., 2024). As shown in (Figure 4) registered vehicles in Pakistan have grown significantly between 2006 and 2018, causing concerns about greater emissions and more congestion, mainly in cities (Asim et al., 2022).

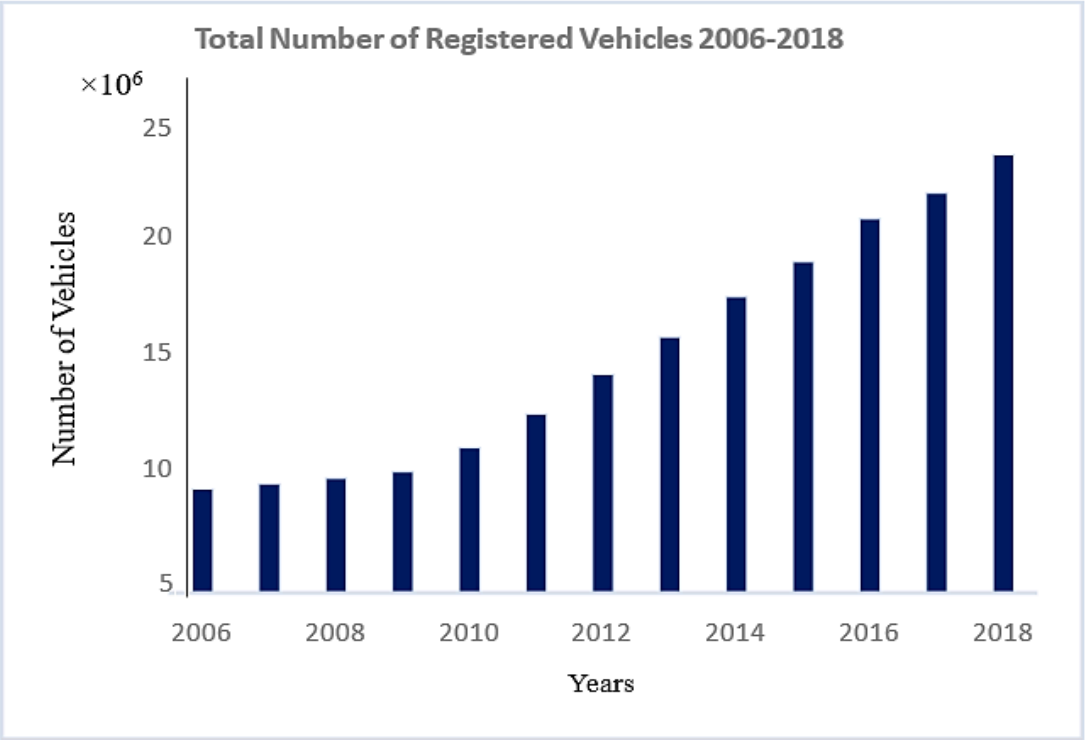

Figure 4. Number of registered vehicles in Pakistan from 2006 to 2018.
Source: (Asim et al., 2022).

As more people use cars in the country, along with their use of gasoline and diesel, the problem of emissions has become much bigger. The report pointed out that, because Pakistan relies on oil and natural gas for transport, its older vehicles use more energy and release higher amounts of pollutants (Kumar et al., 2024; Observatory, 2023). In addition, air pollution around cities such as Lahore, Karachi, and Islamabad gets worse because too many cars are stuck for long periods, releasing extra CO_2 due to wasted fuel (Analytics, 2024; Observatory, 2023).

The assessment of CO_2 emissions in Lahore shows that more cars on the roads are being added faster than new public transportation and roads are being built. As a result, there is much more traffic, higher energy waste and more pollution (Observatory, 2023). According to (Figure 5), energy used in transport increased year after year from 2003 to 2018 mainly because of heavy reliance on fossil fuels and inefficient vehicles (Asim et al., 2022).

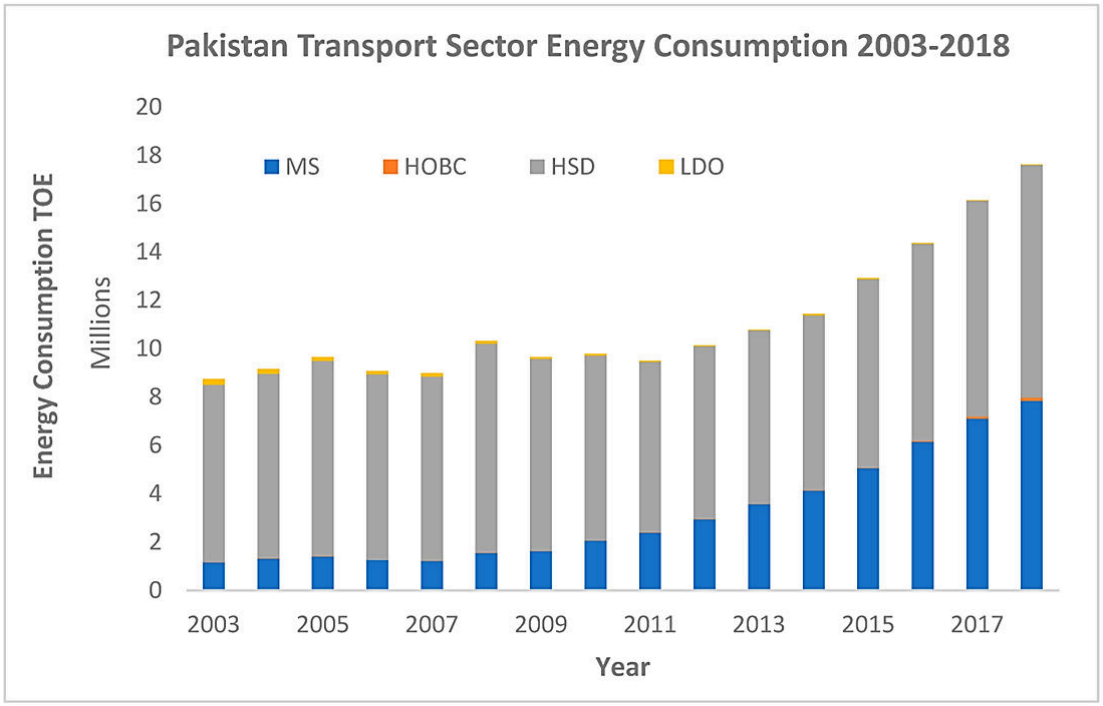

Figure 5. Pakistan Transport sector's energy consumption from 2003-2018.
Source: (Asim et al., 2022).

Contributing to climate change, the transportation sector has serious effects on both the society and health of citizens, mainly in fast-growing cities such as those in Pakistan (Asim et al., 2022; Qureshi, Lu, 2007). As people move to the outskirts of cities, the resulting traffic uses more gas and increases emissions into the air (Arif et al., 2023). Since public transportation in major cities is not well-developed, people have to use private cars, causing mayor traffic jams and higher pollution (Herath Bandara, Thilakarathne, 2025). Due to industrial growth and population increase in Pakistan, more cars are being bought, but because the transportation infrastructure is outdated and cars are inefficient, the sector is moving toward an environmental emergency.

Transportation emissions will still increase due to the rapid growth of cities and insufficient infrastructure, unless quick steps are taken to fix them (Ali et al., 2019; Imran, 2010). Emissions from these fossil fuels cause major economic problems. Based on a World Bank traffic report, missing productivity and wasting fuel amount to about $4 billion annually in Lahore (Bank, 2022). These inefficiencies cause individuals to be less productive and add pressure to the country's economy, mostly in urban areas that support much of the nation's trade, employment and commerce (Herath Bandara, Thilakarathne, 2025).

Emissions from vehicles have led to extra healthcare costs as a result of economic damage caused by air pollution (Ain et al., 2021; Ilyas et al., 2010). As air quality declines, mainly in Lahore, Karachi and Rawalpindi, where many people live, the country's healthcare system is under additional stress, as more patients with respiratory and cardiovascular diseases seek treatment and deepen existing health gaps (Ilyas et al., 2010; WHO, 2023).

Transportation-related pollution is affecting health in a similar major way. Breathing in polluted air because of vehicles has been related to a rise in both respiratory and cardiovascular diseases in Pakistan (Arif et al., 2023; Iqbal, 2020). Figure 6 clearly shows the problems related to air pollution, one of which involves serious cases of respiratory and cardiovascular illnesses in Lahore and Karachi (Khan et al., 2022). As vehicle levels are very high in places such as Lahore, Karachi and Rawalpindi, the pollution sometimes becomes harmful to people's health. WHO reports that air pollution from transportation is responsible for thousands of early deaths each year in Pakistan (WHO, 2023).

People who are children, elderly or have existing problems with their respiratory health are most affected by these pollutants (Herath Bandara, Thilakarathne, 2025; Sarfraz, 2020). Detailed in the Role of Sustainable Technological Innovations report, breathing polluted air raises the number of asthma, lung cancer and heart disease cases which puts more stress on the public health system and decreases national productivity (Parekh et al., 2001). There is no doubt that emissions from transportation harm public health, so new policies must be developed to address air pollution and improve air quality (UNFCCC, 2015).

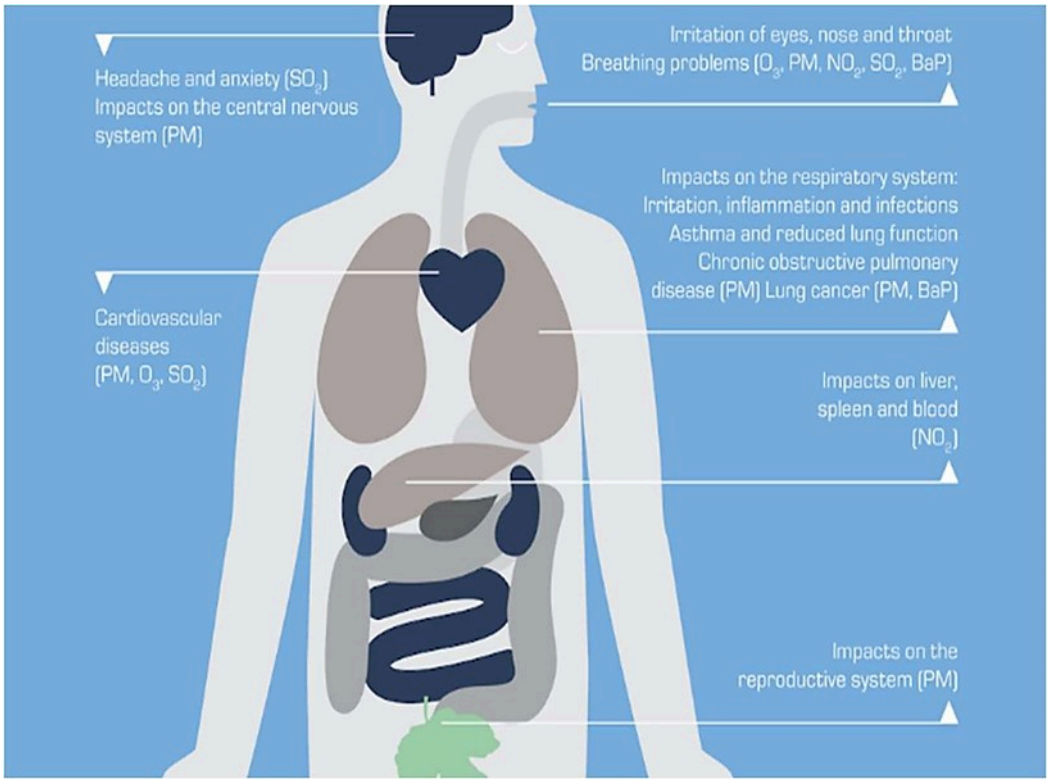

Figure 6. Potential health impacts of major sources of air pollution.

Source: (Khan et al., 2022).

Pakistan faces a higher risk from climate change than many other countries. Asia's geography and certain economic and social weaknesses leave it vulnerable to floods, heatwaves and monsoons that are hard to predict. They create serious threats to both transportation systems and the safety of the public (Bank, 2023; UNFCCC, 2021). Flooding has often damaged

important parts of our infrastructure, causing problems for travel and financially affecting various industries.

According to the Climate Change Vulnerability Assessment Report (2020), flood-prone areas place the roads there at greater risk since they are often blocked during the monsoon (Bank, 2023; UN-Habitat, 2023). In figure 7, the regions hit by flooding along the Indus River in 2014 are shown, demonstrating the risks to Pakistan's transportation infrastructure from extreme weather and identifying places at risk from repeated monsoon floods (Azmat, 2015).

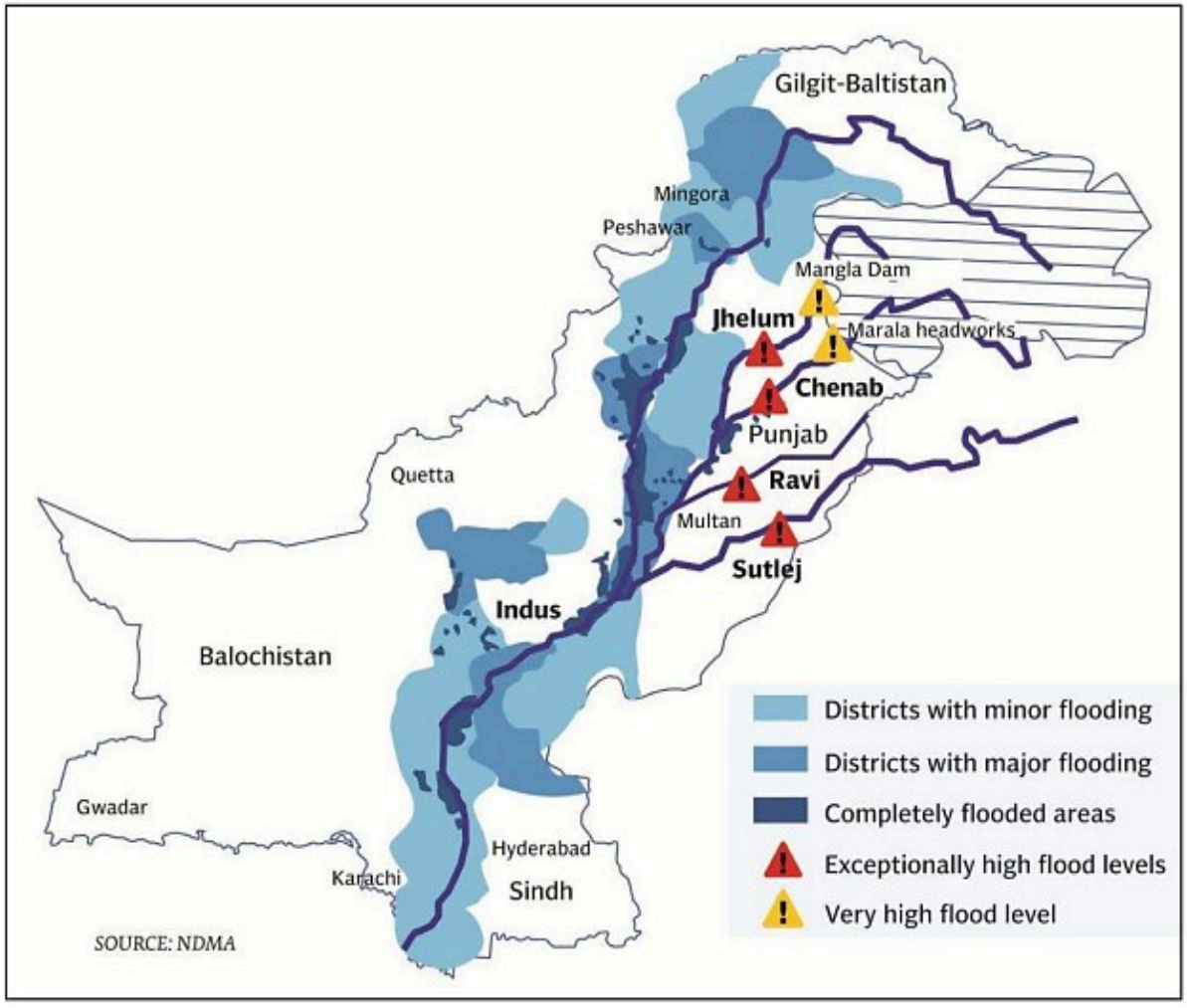

Figure 7. Map showing the flood-affected areas of Pakistan in 2014 and the track of the flood wave along the Indus River.

Source: (Azmat, 2015).

It is predicted that rising heat waves will cause roads and railways to deteriorate more rapidly. Heat can make roads crack and railways bend, which results in serious damage and more money needed for repair (Qin et al., 2022; Regmi, Hanaoka, 2009). Because of these impacts, repairing and maintaining transportation infrastructure due to the climate costs a lot, adding more burden to the country's resources (Bank, 2023; UNFCCC, 2021). The photos in figure 8 highlight the destruction of infrastructure caused by the 2010 floods and reveal why

Pakistan's transport systems need to be more sustainable, as if not, the floods caused widespread devastation (Shah et al., 2020).

Figure 8. Impact of 2010 floods on the infrastructure in Pakistan, the massive rescue & relief mission, and the shelters set up for those displaced in the floods.

Source: (Shah et al., 2020).

To deal with the rising problems caused by emissions from vehicles, Pakistan has begun to use several strategies to bring down its carbon output. The National Electric Vehicle Policy (NEVP) which was launched in 2019, aims to increase the use of electric vehicles (EVs) to cut down pollution in road transport. By 2030, the NEVP aims for EVs to take up a large share of 30% in the country's passenger vehicles (CPDI, 2023; Ministry of Climate Change, 2019). This policy offers tax breaks, helps pay for EV manufacturing and rewards companies developing EV charging, all to push more people to switch to electric vehicles. For now, it is hard to get EVs into widespread use, because of their upfront prices, the shortage of charging stations and people not knowing all about EVs' lasting benefits (CPDI, 2023; Haq, 2019; Unit, 2024).

Along with encouraging electric cars, Pakistan is upgrading public transport to make it easier for people to use it rather than their private vehicles. Bus rapid transit systems and metro lines are being built in Lahore, Karachi and Islamabad to provide economical, efficient, and earth-friendly alternatives for their expanding cities. Private car riders in Lahore are now shifting to the Metrobus system, including the Orange Line Metro which has led to less emissions in the city. The Orange Line which uses its own tracks, has helped decrease traffic

jams and given people a greener form of transportation. Figure 9 highlights where the Metrobus in Islamabad runs and how this supports more riders and better, environmentally friendly city transport planning (Metrohub, 2024). Similarly, efforts are being made by the government to grow both cycleways and walkways to support the idea of using non-motorized transport (NMT). Implementing these projects plays a key role in cutting the carbon gas emissions associated with the transportation sector (Khan et al., 2022; Unit, 2024).

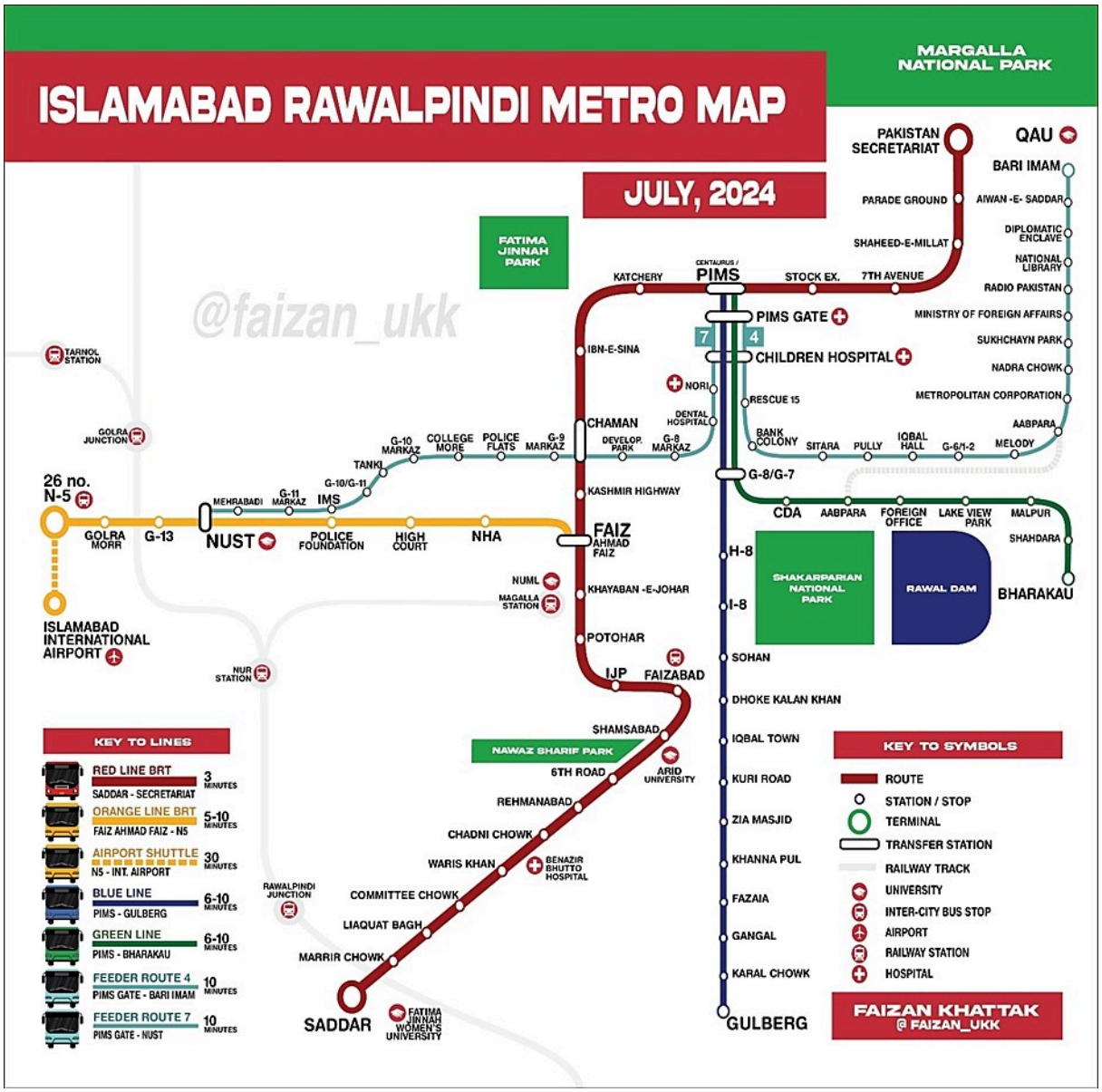

Figure 9. Metro Buses Routes of Red Line, Orange Line, Blue Line and Green Line Metro Service. Source: (Metrohub, 2024).

More people have been using the Islamabad Metrobus service in recent years. The ridership in 2015 was 22,363,321 passengers, and by 2018 it had grown to 40,938,787, reducing only slightly to 37,381,198 in 2019, as you can see in Figure 10. More riders on Metrobuses means the service has encouraged people to use public transport instead of their vehicles. More people using public transport, mainly in cities, helps to lower emissions, ease traffic, and improve the air people breathe (Saqib, Anwar, 2022).

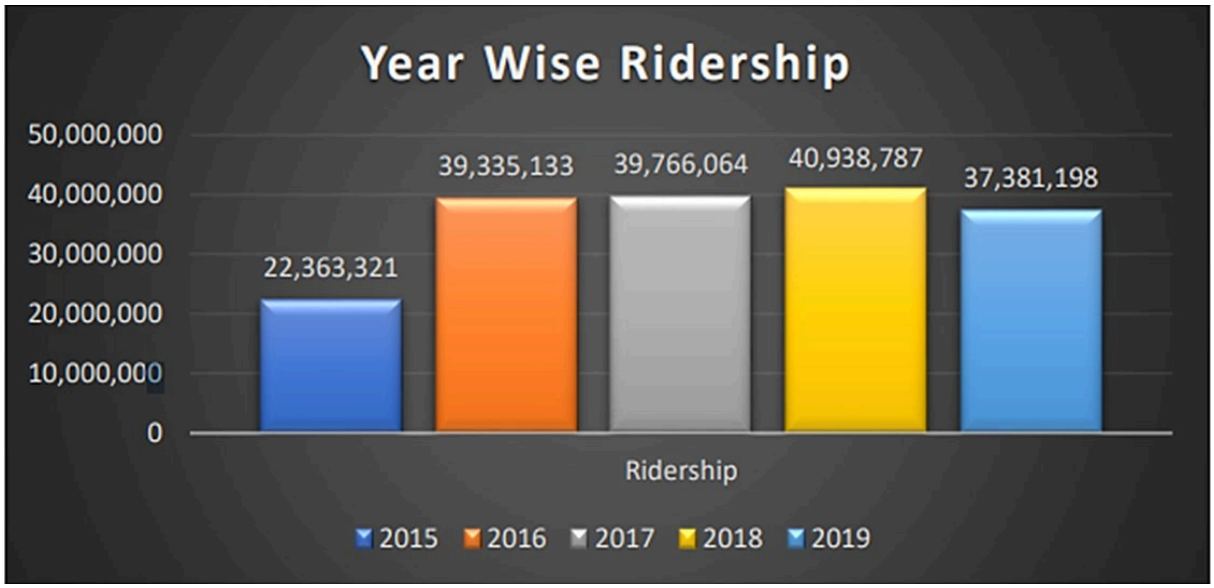

Figure 10. Total ridership of Islamabad Metrobus Services from 2015 to 2019.

Source: (Saqib, Anwar, 2022).

In addition, Pakistan is also working on solar power and other renewable options to reduce how much carbon its transportation units produce. The government's goals for cleaner, renewable energy are supported by using solar panels to charge buses and at stations (Imran, Shutsha, 2024; Observatory, 2023). Using alternative fuels like compressed natural gas (CNG) has worked well to some extent in reducing emissions, but some problems remain, including a lack of refilling stations and changing gas prices (Kumar et al., 2024). While CNG gives us hope now, it's not clear how long it will be useful in the future. Implementing electric vehicles, renewable sources and alternative fuels and boosting cycling and walking, is needed to cut greenhouse gas emissions significantly (Imran, Shutsha, 2024).

Even so, for this to become a reality, Pakistan must deal with its financial and infrastructure problems (Analytics, 2024). This study analyses the part played by transportation in climate change in Pakistan, points out its main sources of greenhouse gases, considers ways to address the issue, and suggests adaptation solutions. It points out that policies and structures should be reformed and new infrastructure must be built to make the transport system more sustainable and better able to cope with climate change. It gives suggestions for policies intended to lower emissions, boost public transit, and deal with the problems of climate change. Making electric vehicles, new fuels, and resilient roadways available is one way to ensure long-term environmental care and lower climate impacts in Pakistan's transportation sector (Analytics, 2024; Imran, Shutsha, 2024; Kumar et al., 2024).

2. Systematic Methodology

To compile this review article, a systematic approach was utilized to identify and investigate sources related to GHG emissions in Pakistan's transportation sector, as well as the approaches and remedies employed to mitigate these emissions. The procedure adheres to the PRISMA workflow's (Chapter 2.7 - Figure 11) standard phases (Page et al., 2021). Firstly, a study question was developed that examined transportation-related emissions, their impacts, and the effectiveness of solutions in Pakistan.

A comprehensive literature search was carried out using Google Scholar, Scopus, Web of Science, and IEEE Xplore databases to locate relevant papers, reports, and studies. The terms searched for are "greenhouse gas emissions caused by transport", "electric vehicles in Pakistan", "ways for reducing transport emissions", "adapting to climate change in transport", or "environmentally friendly transportation in Pakistan" (Chapter 2.7 - Figure 11). Only studies published between 2000 and 2025 were examined in order to get the most recent findings. The time span chosen is intended to document the effects of new technology and policies, as well as how the sector responds to climate change.

2.1. Inclusion Criteria: Only articles that met the following criteria were included:

- Investigations into GHG emissions caused by road, public transit, and freight transport in Pakistan.
- Studies or articles that discuss ways to reduce emissions or create new approaches to manage challenges to transportation infrastructure brought by climate change.
- Articles featured in peer-reviewed journals, conference documentation, or recognized with-standing reports from bodies such as the World Bank, UN Environment Programme, and the Pakistan Ministry of Planning.

2.2. Exclusion Criteria: Articles were excluded if:

They did not focus on issues of GHG emissions, managing them or ways to adapt in relation to transportation in Pakistan. They included sources that hadn’t undergone review by other researchers such as articles expressing opinions or reports without strong methods. They did not concentrate on transportation or had nothing to do with Pakistan. Firstly, 180 articles were identified during the initial search for the study. The titles and abstracts of these articles were used to make the screening decision. Further analysis was done on 122 full-text articles that were selected from the literature. Following the review of the articles against the inclusion and exclusion criteria, 115 articles were selected for further analysis (Figure 11). These articles explained important aspects of emissions, new ways to address them, adapting to climate change and analysing public policy**.**

2.3. Data Extraction and Synthesis

Once the chosen articles were identified, a step-by-step process was followed to collect important information such as what the studies aimed to do, their research procedures, main findings, and recommendations for better emissions management in Pakistan's transport sector. The data was brought together to spot similar topics, like electric vehicles (EVs), compressed natural gas (CNG), and the role of public transportation. They were investigated for their potential to cut transport emissions and to improve society's ability to cope with climate change. Information gaps were discovered in the literature, including not having enough research on the economics of mitigation and adaptation strategies and their long-term success. All of the findings were presented in tables and graphs so that the various measures and their abilities to lower emissions could be easily compared.

2.4. Research Question

This review was guided by the question, "What are the main contributors to GHG emissions in Pakistan's transport system, and what approaches are the most useful for both controlling and coping with them?

2.5. Literature Search

A series of searches was made using Google Scholar, Scopus, Web of Science, and IEEE Xplore. Top search terms were "GHG emissions transportation Pakistan", "electric vehicle adoption in Pakistan", "transportation mitigation strategies", "how Pakistani cities are using public transportation", and "climate action in the transport sector".

2.6. Article Selection

At the outset, articles were shortlisted using only their titles and abstracts, and the chosen abstracts had their full texts reviewed. Criteria used to decide which studies to include covered GHG emissions in transport, the use of EVs, different fuels, public transit services, and policies. Articles not linking directly to transportation or appearing in peer-reviewed journals were not included.

2.7. Quality Evaluation

The quality of the studies was checked by examining their methods, sizes of their samples, fit with the research questions, and how useful their results are. Advanced insights were selected if the studies included standardized measurements and supported them with empirical evidence.

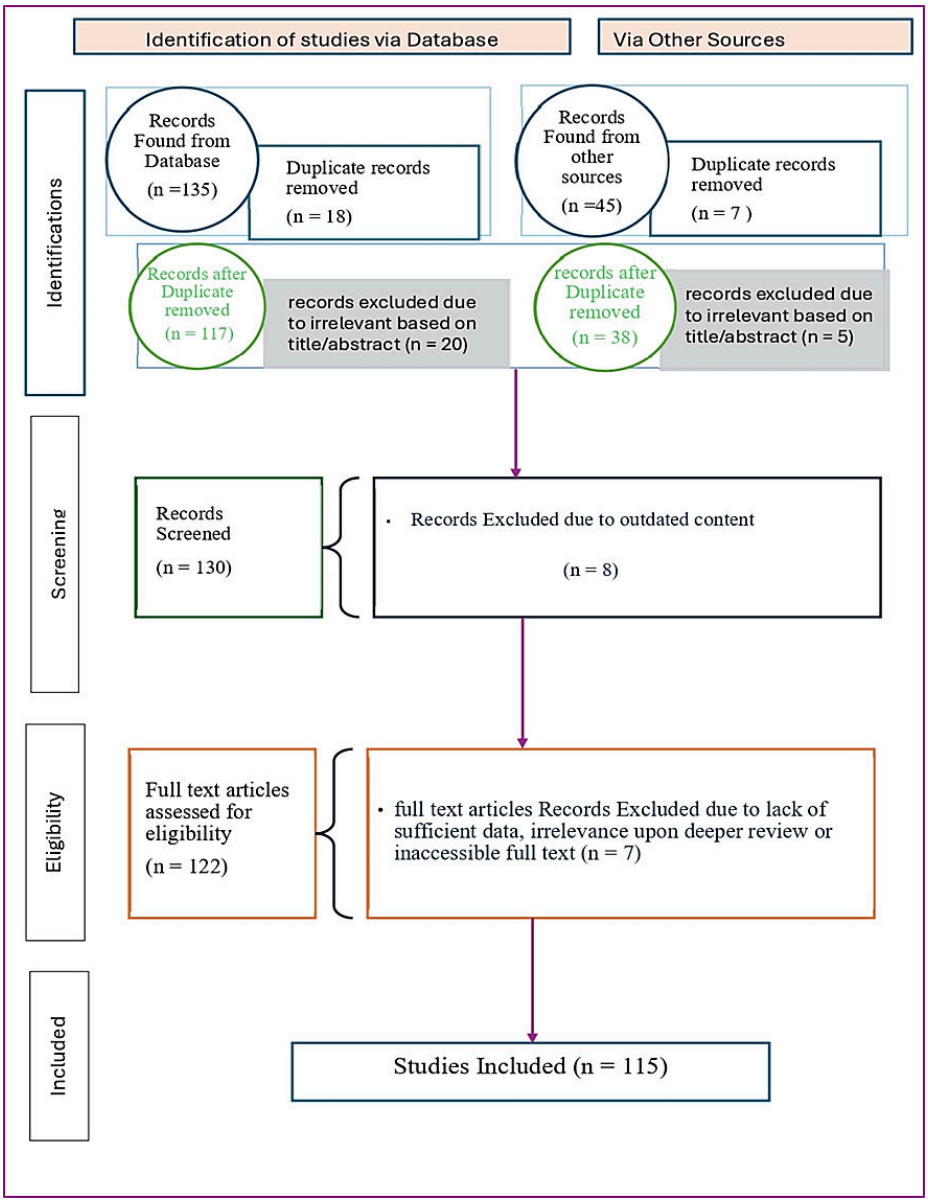

Figure 11. PRISMA Flowchart for article selection process.

3. Greenhouse Gas Emissions from Transportation in Pakistan

The transportation sector plays a big role in adding to Pakistan's greenhouse gas (GHG) emissions. Because it emits a lot of CO_2, it makes an important contribution to climate change. Transportation accounts for an overwhelming majority of Pakistan's GHG emissions, leading to about 98% of the energy sector's emissions, based on several studies (Observatory, 2023). Road transport is the main source of transportation emissions in Pakistan, because it is the most used method of travel (Kumar et al., 2024; Saqib, Anwar, 2022; Transparency, 2020). The main reason is that there are too many private cars and freight vehicles which perform poorly in fuel economy and pollute the environment (Analytics, 2024; Kumar et al., 2024). Pakistan's

transportation sector is mainly reliant on road transport which is also its main contributor to pollution (CDKN, 2023; Observatory, 2023).

3.1. Sources of Emissions

According to the Assessment of Sustainability of Freight Transportation in Pakistan, the sector's main source of CO_2 emissions is private vehicles and freight transport (Observatory, 2023). City areas like Karachi, Lahore, and Islamabad, where traffic often stacks up, make the emissions issue worse. Because many cars are packed on the roads, inefficiencies caused by old and rundown vehicles increase fuel consumption and CO_2 emissions (Kumar et al., 2024). The biggest part of urban emissions comes from cars, motorcycles, and small trucks. Because traffic is so congested in Karachi and Lahore, private cars cause more than their share of greenhouse gas emissions (Observatory, 2023; Tariq, Ali, 2017).

A further study by Spatiotemporal Assessment of CO_2 Emissions finds that the vehicle densities in these cities are among the highest in the country, which means their residents produce more emissions relative to others (Ilyas, 2007). Using a lot of private vehicles means more energy is wasted and there are higher emissions, due to poor traffic organization and infrastructure (Tariq, Ali, 2017). From the data in (Table 1), road transport accounts for most of Pakistan's transport-related CO_2 emissions for 2022, representing 97.9% of the sector's emissions. Similarly, rail, aviation, and domestic navigation play a small role, revealing the need for urgent changes in road-based transportation (Saqib, Anwar, 2022).

On the other side, the inefficient fuel use by long-haul trucks means their freight transport activities add significantly to emissions. The Assessment of Sustainability of Freight Transportation indicates that freight transportation uses up more fuel and emits relatively more gas than passenger vehicles (Observatory, 2023). Often built years ago and treated poorly, these large trucks emit large levels of diesel fumes and cause high amounts of CO_2, nitrogen oxides (NO_x), and particulate matter to be released (Kumar et al., 2024). This situation is a major obstacle to achieving Pakistan's sustainability aims (Observatory, 2023).

Table 1.
Share of CO_2 emissions by different transport sectors in Pakistan in 2022

Transport Mode	Share of Transport CO_2 Emissions (2022)	Key Details
ROAD (ALL TYPES)	97.9%	Includes private vehicles, freight trucks, buses, and motorcycles
RAIL	1.7%	Minor share, mostly passenger and some freight
AVIATION (DOMESTIC)	0.4%	Includes domestic air transport
SEA/NAVIGATION (DOMESTIC)	0.0%	Negligible for domestic emissions

Source: (Saqib, Anwar, 2022).

3.2. The Role of Urbanization

The rapid growth of cities in Pakistan has greatly increased transportation emissions in recent years. The population living in cities has gone up, resulting in a greater demand for travel all around, especially in Lahore, Karachi, and Islamabad (Ilyas, 2007; Tariq, Ali, 2017). According to Urbanization Effects on Temperature Trends of Lahore During 1950-2007, the rise in transportation due to urbanization has boosted CO_2 emissions in Lahore (Sajjad et al., 2009). Growing urban places have caused more cars to travel on roads, which has increased the amount of fuel used and the amount of greenhouse gas released (Ilyas, 2007).

A big part of the issue is that public transportation is not accessible enough. It is proving increasingly hard for cities to establish mass transit as people use more and more personal cars (Observatory, 2023). The Figure 11 highlights that the rising urban population in Pakistan leads to an increased amount of emissions (Tariq, Ali, 2017). Because public transport is limited in places like Lahore, the number of cars on the roads is going up. As a result, the problem has grown more serious, as people often drive themselves to work and other places (Ilyas, 2007).

It gets even worse because urban sprawl means people depend more on their cars, leading to greater fuel use and higher CO_2 emissions (Sajjad et al., 2009; Tariq, Ali, 2017). As people keep moving to cities, the need for personal cars gets bigger. This trend makes our environment suffer more. In addition to producing CO_2, vehicle exhausts also release nitrogen oxides (NO_x) and carbon monoxide (CO), causing problems in urban atmosphere and for people's health (Ilyas, 2007; WHO, 2018).

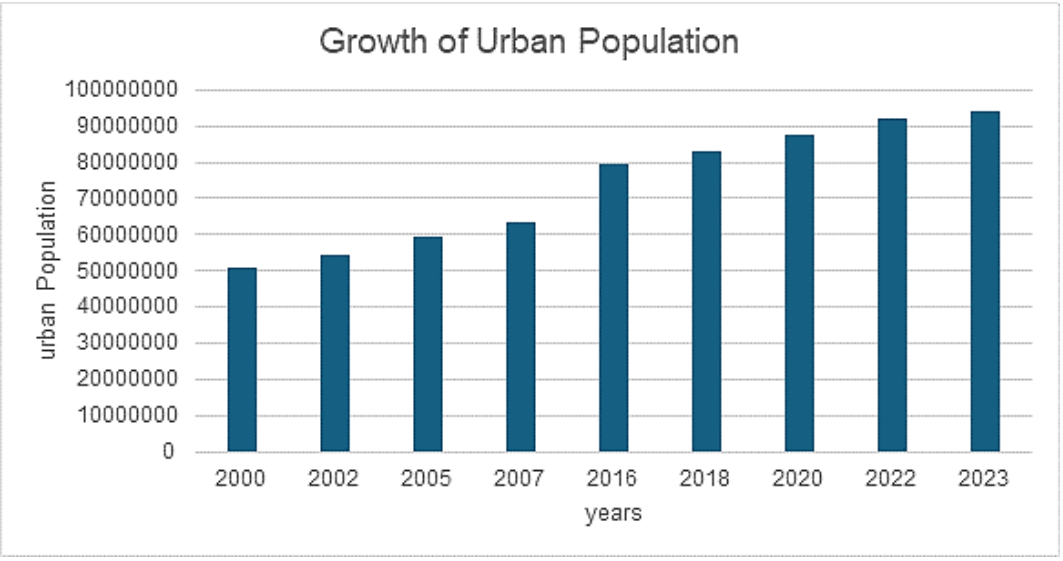

Figure 11. Growth of Urban population in Pakistan from 2000-2023.
Source: (Bank, 2022).

3.3. Fuel Efficiency and Vehicle Fleet Age

Efficiency issues with the country's vehicles are a major reason for transportation emissions in Pakistan. Most of the country's cars are older and usually not well taken care of, resulting in them using extra fuel (Kumar et al., 2024). The report Impact of Green Energy Transportation Systems on Urban Air Quality found that switching to fuel-efficient vehicles can lessen the use of CO_2 (Ilyas, 2007). But, because Pakistan's cars are often older and regulations are lenient, both fuel consumption and emissions keep getting higher (Observatory, 2023). The efficiency of fuel use in Pakistan depends greatly on how old the fleet of vehicles is. Because old vehicles tend to burn more fuel and release more pollutants, this problem affects commercial and freight vehicles, as many of these vehicles are decades old (Kumar et al., 2024). Most of them do not meet the current emission standards which means they use too much energy and pollute the environment (Analytics, 2024).

To increase fuel efficiency, the government of Pakistan has introduced stronger emission rules and encouraged more EVs. Nonetheless, the high cost of owning an electric vehicle, insufficient charging stations and slow acceptance by the public continue to block widespread use of greener technology (CPDI, 2023; Unit., 2024). According to the report, Pakistan's government has started giving incentives to people who buy EVs such as eliminating import taxes and exemptions from paying taxes (Ministry of Climate Change, 2019). Even so, insufficient charging stations and a lack of knowledge about the environment among people are slowing down the use of EVs (Unit, 2024).

3.4. Emerging Solutions and Challenges:

Even though the causes of emissions from Pakistan's transport are known, there are now solutions and strategies to tackle these issues. NEVP outlines that the EV industry is one of the most effective methods for lowering carbon emissions in the sector. Incentives for EVs encourage Pakistan to change from cars powered by fuel to electric vehicles which create fewer emissions (Ministry of Climate Change, 2019). Compressed natural gas (CNG) is proposed as another alternative since it is thought to be cleaner than cars burning gasoline and diesel. CNG, as explained in International Experience with CNG can lower CO_2 emissions most significantly in cities with a lot of traffic. Still, problems such as not enough CNG stations, changing prices for natural gas and lack of required infrastructure (CDKN, 2023; Observatory, 2023).

4. Mitigation Strategies

4.1. Electric Vehicles (EVs)

EVs are considered a great solution for cutting down emissions from the world of transportation. EVs eliminate gasoline or diesel dependency, meaning they do not directly burn fossil fuels that create much of the CO_2 emissions in standard vehicles (IEA, 2023; Kumar et al., 2024). Electric cars play a major role in reducing Greenhouse Gas Emissions since they do not exhaust from the tailpipe and the degree of reduction depends on the source of energy the cars use for charging (IEA, 2023).

Although EVs have taken time to gain popularity in Pakistan, progress is becoming noticeable. Light-duty vehicles make up a larger share of electric vehicles in the market now than they did in 2017 (CPDI, 2023).The Pakistani government understands how important EVs are and has now introduced the National Electric Vehicle Policy (NEVP) to encourage people and companies to use EVs through tax, duty, and subsidy incentives. Pakistan aims to have 30% of all cars on its roads be electric by 2030, putting priority on both passenger and commercial automobiles (Ministry of Climate Change, 2019).

But, despite the attempts, EVs are not widely used in the country yet. A number of problems are blocking EVs from becoming more common, such as their high initial costs, insufficient charging stations, and the need for additional policy support (CPDI, 2023; Unit, 2024). To many consumers, EVs are not attractive because expensive batteries used in them and the fact that most are made overseas make them costly (Kumar et al., 2024). The presence of a small number of charging stations has made many people hesitant to use electric cars because of what we call range anxiety (Unit, 2024).

The list in table 2 proposes locations for EV charging stations on the major highways in Pakistan and lists the coordinates and distances between each location. It marks a primary and vital milestone on the way to setting up a national EV network. With location on the N5 and M2 highways, these sites are vital for both practical and dependable electric vehicle travel across long distances (Khan et al., 2021). Pakistan's electric vehicle system is just starting up and it requires more significant effort to build a charging network across the country. Based on the Transforming the Transportation Sector report, adding more charging stations, making EVs more affordable and giving out incentives to buy and manufacture EVs is vital for EVs to gain traction (CPDI, 2023; Kumar et al., 2024).

In time, more EVs may protect the environment, especially if the electricity being used comes from renewable sources. Because of this, the whole process of building and using an EV, including charging, will stay low-carbon, so switching to EVs is a key part of Pakistan's overall climate strategy (Khan et al., 2021).

Table 2.
Proposed Charging Station Locations and Distance

Sr. No.	City	Longitude, Latitude	Distance
A	**N5 network**		
1.	Rawat	32.4805288, 72.687214	15.7
2.	Mandra toll plaza	32.4277489, 72.40935	59
3.	Deena	33.0285967, 73.598110	20
4.	Sarae Alamgir	32.907611040865, 73.730340115134	8
5.	Kharian	32.8830768, 73.7785187	46
6.	Gujrat exit	32.5959182, 74.0378919	9
7.	Gujrat	32.4797136, 74.091663	10.3
8.	Wazirabad	32.4026824, 74.1224383,	13.5
9.	Gakhar	32.317067, 74.143303	13.6
10.	Gujranwala		17
11.	MoreAimanAbad	32.0488448, 74.2085573	11.4
12.	Kamoke	31.995427755973, 74.218015463522	11
13.	Sadhoke	31.862328, 74.24472	12.7
12.	Muridke	31.6420817, 74.2032471	11.4
15.	Kala Shah Kaku	31.7338073, 74.2655666	46.2
B	**M2 network**		
16.	Chakri	33.3203856, 72.7829902	45
17.	KalarKahar	32.869405, 72.65204	73.5
28.	Bhera	32.453259538502, 72.886018340599	46.5
19.	Sial Mor	31.9680162, 73.1120396	77.5
20.	Sukheki	31.906767165001, 73.56816594500	48.6

Source: (Khan et al., 2021).

4.2. Compressed Natural Gas (CNG):

For years, Pakistan has used CNG as a way to reduce pollution by using it instead of petrol and diesel. CNG releases less CO_2 and NO_x, and PM than traditional fossil fuels like diesel or gasoline (Yasar et al., 2013). International Experience with Compressed Natural Gas (CNG) as an Environmentally Friendly Fuel states that CNG can be a useful alternative that cuts emissions in cities such as Lahore, Karachi, and Islamabad (Shah et al., 2020).

The cost difference between CNG and other fuels is one reason why people find it a desirable choice. Besides, Pakistan produces CNG in its own country, saving the nation money from buying oil. Compressed natural gas technology is already in place on public transports like buses and rickshaws in some locations to minimize city pollution and carbon emissions (Observatory, 2023).

Table 3 compares emissions from CNG, diesel, and gasoline cars to show CNG's advantages. Diesel buses emit a lot of smoke and hydrocarbons, with their opacity reaching 51% in smoke and reaching 21,000 ppm in hydrocarbons. CNG buses, by comparison, emit less smoke and far fewer hydrocarbons, their opacity reaching 16% and hydrocarbon emissions measuring around 1500 ppm. NO_x and SO_2 emissions are lower by comparison across all CNG vehicles, proving that CNG is much safer for the environment than conventional fuels (Yasar et al., 2013). These results demonstrate that the use of compressed natural gas benefits air quality, mainly in crowded city areas.

Nevertheless, using CNG is not common because it has issues with infrastructure and its price switching. Because CNG refuelling is rare in many rural regions, it's not a good fuel choice for travelling far from the cities. Also, because the price of natural gas changes, choosing natural gas for fuel may not be financially sound (CDKN, 2023).

Expanding the network for CNG will motivate more people to use it instead of other fuels. Minimizing the travel distance to CNG stations through better access from principle highways and rural areas might encourage more CNG users. Taking CNG as a cleaner alternative, government can also provide subsidies for cars that use CNG and grant tax exemptions to CNG fuelling sites (Yasar et al., 2013). CNG could act as a temporary answer for a few years, until the national shift to electric cars and renewable energy is fully developed (Unit, 2024).

Table 3.
Comparison of different mean emissions by different vehicles

Vehicle Type	Fuel Type	CO (%)	NO (ppm)	SO_2 (ppm)	Smoke Opacity %	HC (ppm)
Bus	CNG	2	45	22	16	1500
	Diesel	0.1	82	120	51	21000
Rickshaw	2-stroke LPG	3.5	2	55	47	13000
	4-stroke CNG	2.5	21	25	10	700
	4-stroke Gasoline	2.6	15	30	16	3100
Van	CNG	1.3	60	23	24	1350
	Diesel	0.15	78	115	40	19000
	Gasoline	2.4	75	28	22	4200
Motorcycle	2-stroke gasoline	4.7	21	45	21	6200
	4-stroke gasoline	1.6	16	21	12	1500
Tractor	Diesel	0.4	110	120	38	20000
Truck	Diesel	0.2	120	123	54	22000
Car	CNG	1.6	16	25	5	610
	Diesel	0.1	45	125	30	15000
	Gasoline	1.8	13	31	6	2800

Source: (Yasar et al., 2013).

4.3. Public Transportation and Non-Motorized Transport (NMT)

One way to decrease traffic-related emissions is to widen options for public transport and support the use of walking and biking. Using buses, metro systems, and light rail is a good way to decrease our use of private cars. This then reduces the use of fuel and emissions by lowering traffic on the streets (Ilyas et al., 2010; Qureshi, Lu, 2007). A boom in city dwellers can be met by using mass transit and NMT, which can help control rising greenhouse gas emissions caused by cars (Ali et al., 2019). Trains, buses, and BRT systems, for example, allow people to move quickly and at the same time help improve the air quality and reduce traffic (Ilyas, 2007; Qureshi, Lu, 2007). As figure 12 illustrates, new bike lanes have been built alongside the Metrobus line to support more people walking and cycling (News, 2025). These projects facilitate switching between various transportation methods and lower daily carbon emissions in highly populated areas.

Moving from personal cars to public systems can play a vital part in Pakistan's efforts to reduce climate change. As of 2013, the Lahore Metrobus System has led the way in making transport cleaner for the city. The Metrobus has solved several transportation problems, making travel easier and helping reduce crowded streets in one of Pakistan's high-density cities. The Sustainability Assessment of Modern Urban Transport points out that the Metrobus system has brought down emissions by taking 200,000 passengers a day off city streets instead of using their own vehicles (Ilyas, 2007). Fewer cars on the road and a green system for urban travel have lowered CO_2 emissions. At the same time, setting up these facilities in other cities across Pakistan would help Pakistan reduce emissions and achieve greater sustainability in transportation (Qureshi, Lu, 2007).

Figure 12. Construction of Bike Lanes along with a dedicated metro bus lane in Lahore.
Source: (news, 2025).

Adding cycling and walking to public transport helps lower emissions as well. Places such as Lahore and Karachi have started to realize that more cycling lanes and walkways for pedestrians are needed (Ali et al., 2019). Linking non-motorised transport(NMT) infrastructure to public transport can provide an overall, sustainable way for cities to move people (Ilyas, 2007). Using cycling and walking gives non-motorised transport(NMT) an easy way to save fuel and cut down on congestion and pollution linked to motorized trips (Ali et al., 2019).

Using non-motorised transport (NMT) in urban planning encourages cleaner cities and also improves public health because more people are active. Strong growth in urban transport use requires an increase in mass transit services and putting non-motorised transport (NMT) in the forefront to keep transportation emissions under control in Pakistan. Using public transport means lower carbon emissions and helps address longstanding traffic problems found in metropolitan areas. With the help of better non-motorised transport (NMT) infrastructure, Pakistan can become a low-emission country that meets climate targets and helps cities become greener (Ilyas, 2007; Qureshi, Lu, 2007).

4.4. Challenges and opportunities in mitigation strategies

While these methods for reducing emissions from transportation in Pakistan look promising, there are many obstacles that must be addressed to ensure they work well. The main reason electric vehicles (EVs) and compressed natural gas (CNG) vehicles are not more popular is the shortage of supporting infrastructure. Electric cars must be charged at many locations, but CNG cars encounter problems with finding and accessing fuelling stations. Because there is not enough infrastructure, it is both costly and difficult to improve SUV fuel efficiency (CPDI, 2023; Observatory, 2023).

Another important challenge is that electric vehicles are very expensive to buy, so the average consumer in a low-income country often cannot afford one. People have to pay a lot up front for EVs, even with the government incentives that are designed to lower prices. Furthermore, not many consumers are aware of the lasting advantages of EVs such as spending less on fuel and upkeep by using them, so less people are buying them. Widening awareness and education efforts are required to have more people use EVs which could help the government accomplish their set goals (CPDI, 2023; Unit, 2024).

At the same time, it is difficult to implement lasting mitigation strategies because of political and regulatory issues. Pakistan has not fully developed its policies for the environment and climate resilience and there can be gaps in the government's strong commitment to them. Stringent and well-managed regulations in clean transport such as emissions limits and vehicle laws, are needed to achieve major emission reductions. Also, because government agencies handle decisions separately, it can reduce the effectiveness of strategies used to address climate change in the transportation system (Ilyas, 2007; Tariq, Ali, 2017).

Still, many possibilities can make a difference and promote progress. Developments in EV battery technology and adding renewable energy to EV charging stations are promising answers to these problems. Making EV batteries less expensive and boosting the charging system will improve access and affordability for EVs. Integrating solar and wind sources at EV chargers can shrink the amount of carbon released by cars and other vehicles. Because of the large amount of renewable energy available in Pakistan, there is a big chance for clean energy to drive its transportation system, turning the country into a leader in this area (Kumar et al., 2024; Nadeem et al., 2022).

In addition, public-private partnerships (PPPs) hold the promise of addressing problems related to finances and infrastructure. Working together with private groups, the government can facilitate the creation of more forms of mass transit, more EV charging stations and alternative fuel stations. By collaborating, nations can support the investment needed to build green technologies and the proper infrastructure to achieve climate targets. Having more EVs and CNG vehicles produced locally would make importing easier, bring jobs, and make moving toward cleaner vehicles easier on the economy (CPDI, 2023; Observatory, 2023).

Implementing cycling and walking as key parts of city planning can do much more for the sustainability of transportation. Eco-conscious cities that encourage NMT can improve the health of their communities by encouraging exercise and cutting air pollution. With this strategy, cities can lessen traffic jams, use less fuel, and help people lead more sustainable ways of life. Facing and benefiting from available solutions is key for Pakistan to successfully put into action mitigation measures. Proper investments in infrastructure, technology, and policies can guide the nation through the tough process to a low-carbon and climate-adaptable transportation sector (Ali et al., 2019; Ilyas, 2007).

5. Adaptation Measures

In response to the current impact of climate change on ecosystems and human life worldwide, the transportation sector must implement robust adaptations. In Pakistan, the resilience of the transportation sector is crucial as climate change brings increasingly extreme weather conditions like heat waves, floods, and unusual rainfall patterns (Bank, 2023; UNFCCC, 2021). In order to prepare Pakistan's transportation sector for climate change, this section examines two essential steps: strengthening infrastructure and taking climate change into account while planning. The objective is to ensure that Pakistan's transportation system can adapt to the consequences of climate change while maintaining its functionality (Bank, 2022; UN-Habitat, 2023).

5.1. Climate-Resilient Infrastructure:

Pakistan’s transport system is at high risk from climate change. Adverse weather such as heavy rain, floods and heatwaves can seriously weaken and shorten the working life of roads and bridges. The Divisional Disparities’ survey on Climate Change demonstrates that building infrastructure that can cope with these disturbances is key. Because more land is being developed and climate extremes are increasing, infrastructure that can stand up to climate conditions is necessary (Ilyas, 2007; Tariq, Ali, 2017).

Climate-resilient roads and bridges should always be designed to resist flood damage. Flooding is a regular problem for many regions in Pakistan, mainly in low-lying areas, during the monsoon season. The situation leads to problems with road access and unsafe journeys. The Divisional Disparities report emphasises that roads and bridges should be built to withstand rain and floods by following flood-resilient standards. They make use of water-resistant materials, elevated roads and drainage systems built to stop water from gathering on transport routes (Ahmed et al., 2021; Ilyas, 2007).

Extreme heat can cause many difficulties for the movement of people and goods. When it's hot, roads and pavements may become softer, so they develop cracks and ruts. High-temperature materials and shift in roadway design are important tools to minimize heat effects. Bridges and overpasses should be designed so they don't warp or bend from intense heat, so that they don't lose their strength (Tariq. Ali, 2017; Zeeshan, Iqbal, 2022).

Besides, modern drainage systems must be added to avoid floods that may happen during rainy days. Karachi and Lahore's drainage is inefficient and water problems and traffic becomes worse. Enhancing drainage is a key step in strengthening transportation against heavy rainfall (Ahmed et al., 2021; Ilyas, 2007).

Using sustainable materials is very important in ensuring infrastructure is resilient to climate change**.** Taking advantage of recycled asphalt and concrete in infrastructure is a way to save the environment and enhance the strength of critical roads and bridges. When green corridors and vegetative cover are added to designs for cities, the use of these materials can make transportation systems more resilient (Ilyas, 2007; Zeeshan, Iqbal, 2022).

Figure 13 proposes a way to include climate resilience in transportation planning and infrastructure in Pakistan by offering an approach that includes analysing climate risks, setting up strong design guidelines, bringing together relevant organisations and thinking ahead about sustainability (Khan et al., 2016). It highlights that planning early and involving a range of people is important to improve the infrastructure's resilience to future climate risks.

Figure 13. Resilient design initiatives.

Source: (Hyder et al., 2024).

5.2. Climate Change in Transport Planning

Transportation plans should include strategies for responding to climate change to help the system stay strong over many years. In Pakistan, the risks from climate change must be analysed at the start of each transportation initiative. Climate Change and the UN-2030 Agenda note that considering climate risks in transport planning allows us to find weaknesses and provide additional protection from changing climate hazards (Iqbal et al., 2024; Nafees et al., 2024). Projections about climate change, covering changes in rain, temperature and extreme events, are important for transport planning (Ali et al., 2019).

As a result, strategies can be developed to keep transportation infrastructure working even as the climate changes. For instance, road and bridge planning in flood-risk areas should address the rising scale of flooding and transportation networks should be built to survive extreme temperatures and heavy rain. Refurbishing current transportation facilities is a key aspect of responding to climate change. It is possible that the designs of our roads, bridges and transportation systems do not consider climate issues. Improving the resistance of these systems to the effects of climate change is necessary (Nafees et al., 2024). This requires increasing roads, strengthening drainage and choosing building materials designed to withstand all kinds of weather. By adding climate-resistant parts to already established infrastructure, its value can last longer, and damage due to climate change can be cut down (Iqbal et al., 2024).

In addition, switching to climate-resistant public transportation is crucial. Building more metro buses and light rail lines, together with more attention to cycling and walking, can cause people to use private cars less, cut down on emissions and lower traffic pile-ups (Iqbal et al., 2024; Nafees et al., 2024). They must be made to stand up to climate stress, so stations are enclosed, tracks are raised, and vehicles are strong enough to run in any weather (Nafees et al., 2024).

5.3. Policy Integration and Planning for Adaptation

Pakistan's climate-resilient transportation infrastructure will succeed most if adaptation strategies are integrated into both national and local policies. Policymakers should ensure that climate adaptation is given top priority in both developing transportation and planning cities. It is important to integrate climate change thinking at every stage of building, maintaining and operating infrastructure (Khan et al., 2023; Tariq, Ali, 2017). A detailed strategy to reduce climate change impacts is found in the national adaptation plan (NAP), especially in the context of ensuring the transportation sector is strong and reliable. The NAP points out that infrastructure must be designed to handle the rising number and intensity of climate-related problems, including flooding, heatwaves and bad weather (Khan et al., 2023; UNFCCC, 2021).

Figure 13 describes a suggested process for developing an action plan using Pakistan's climate change policy and including it in transportation planning. A basic process is outlined, starting with evaluating weaknesses, improving teamwork among institutions and preparing

adaptation plans, then moving to project implementation, keeping an eye on results and updating policy implementation (Khan et al., 2016). It points out that climate adaptation needs to be included in all transportation policies from local to national governments.

Also, regular cooperation between each level of government and teaming up with relevant business leaders is required to ensure the successful execution of adaptation measures. Because of these divisions, adaptation policies can be adapted for each region's special needs and vulnerabilities. Places like Karachi and Hyderabad, which experience flooding, ask for special action to enhance the security of their transportation systems. Some of the steps these interventions involve are raising roads, better managing storm drainage and making sure bridges can handle harsh weather (Ali et al., 2019; Khan et al., 2023). Local solutions must be based on information from the region, its climate and what communities suggest, so that the adaptation steps are appropriate and can be sustained (Tariq, Ali, 2017).

The development of climate-resilient roads and bridges is made possible by using different financial mechanisms. Climate financing from the World Bank, the Green Climate Fund (GCF) and UN Climate Change should be actively sought by the government in Pakistan (Bank, 2022; Khan et al., 2023). They may also help to build major projects that will protect us from climate change, for example, flood-proof roads and bridges and climate-safe transport systems. Just as well, getting the private sector involved through public-private partnerships (PPP) can greatly speed up efforts to adapt to climate change. Points of agreement between public and private organisations can add innovation, experienced staff and funds to build green infrastructure quickly and ensure its sustainability (Observatory, 2023).

Working together, public and private organisations can greatly increase Pakistan's efforts to develop a strong transportation network that can face climate-related changes. Improving expertise and knowledge exchange between all officials and involved parties is important too. It covers teaching engineers and urban planners about climate resilience, strengthening the capacity of local authorities to plan for changing climate risks and encouraging partnerships for sharing strategies on making infrastructure more sustainable (Khan et al., 2023; Tariq, Ali, 2017). By taking such a wide approach, Pakistan's transport system will be able to resist the effects of climate change and continue to aid the economy and improve living standards (Khan et al., 2023; UNFCCC, 2021).

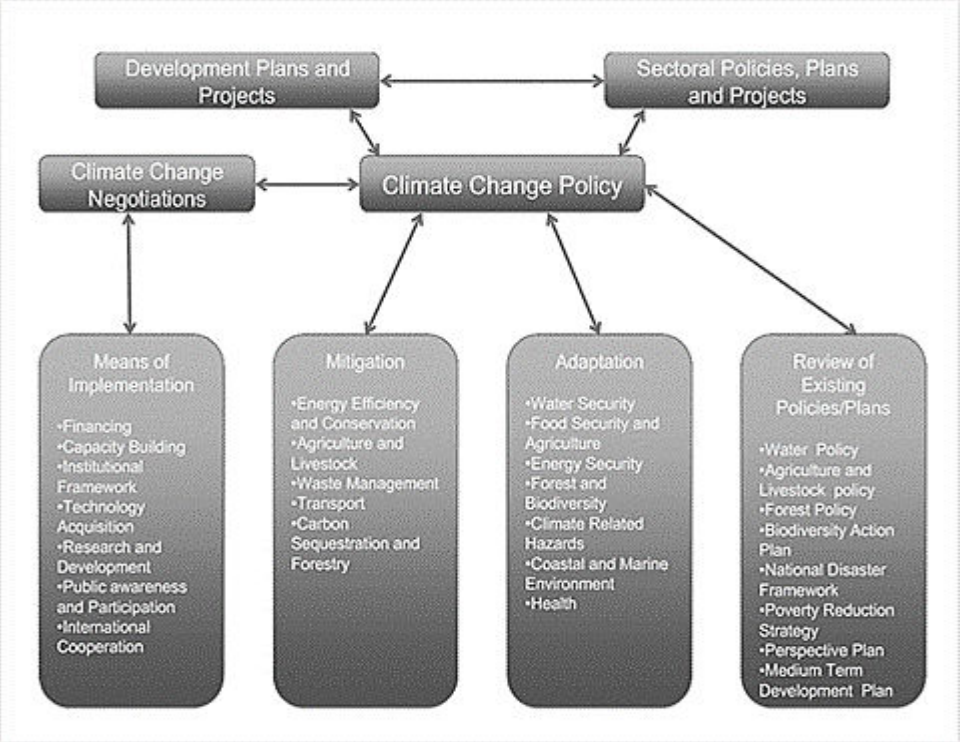

Figure 13. Proposed framework for the development of an action plan based on the climate change policy of Pakistan and its integration in the planning process.

Source: (Khan et al., 2016).

5.4. Challenges in Implementing Adaptation Measures

Addressing climate-related problems in Pakistan's transportation requires efforts on both a structural and organisational level. A main challenge is that there isn't enough funding to finance major improvements to infrastructure. It is necessary to spend a lot on roads and bridges that resist flooding and on building climate-resilient urban transportation. At the same time, Pakistan struggles to find funds because its budget is stretched in many other directions (Khan et al., 2023; Tariq, Ali, 2017). Things become more difficult because political and institutional issues make coordinated adaptation planning challenging. Because federal and provincial governments are not always in agreement, policies can vary widely from one area to another (Khan et al., 2023; Observatory, 2023). Furthermore, weak systems for checking and guiding climate adaptation work lead to problems in spending resources and delaying the start of projects.

Having the needed technical capacity presents a major difficulty for Pakistan's adaptation strategy. To create and use climate-safe infrastructure, people must have experience with sustainable building, tackling floods and adding electric vehicles and alternative energy sources to the transportation system. Having a shortage of skilled and technical personnel prevents countries from creating strong adaptation strategies (Tariq, Ali, 2017).

Moreover, the main political and economic issues of the moment often get in the way of long-term plans for dealing with climate change. Since the government's focus is on fast economic improvements, it does not always prioritise the bigger goals needed for resistance to climate change (Khan et al., 2023). This makes it harder to keep political attention on climate adaptation in the long run.

Addressing these issues requires the introduction of public-private partnerships, climate bonds and climate finance programs fostered internationally. Integrating climate adaptation plans into development plans at the national and provincial levels improves the government's commitment and leads to better and more consistent actions (Bank, 2022).

Additionally, both the public and private sectors must build their capacities to give key stakeholders the necessary knowledge and skills for designing and finalising climate-resilient infrastructural investments (Observatory, 2023). Stronger systems for governing climate adaptation and more cooperation across all government and private sectors are also vital for overcoming obstacles and seeing the planned efforts through (Khan et al., 2023; Tariq, Ali, 2017).

6. Case Studies: shifting from Private vehicles to Public Urban Transport for GHG Reduction in Pakistan

The growth of cities and cars in Pakistan has significantly increased GHG emissions, polluted the air, and led to more traffic jams (Bajwa, Sheikh, 2023). Consequently, main cities have developed mass transit to encourage commuters to use public transport instead of their cars and reduce harmful emissions from transportation (Saleem et al., 2022). This section examines specific case studies from Peshawar, Karachi, Islamabad-Rawalpindi, and Lahore to determine the extent to which these actions reduced GHG emissions.

6.1. Lahore Metrobus and Orange Line Metro Train

The Lahore Metrobus System, which started in 2013, was Pakistan's first bus rapid transit system (Rathore, Ali, 2015). Over 150,000 passengers are served by the Metro line's approximately 27-kilometre section daily (Aziz, 2015). Since the MBS started, private vehicle use has gone down by 15%, which has resulted in about a 31,000-ton annual reduction in CO_2 emissions (Iqbal et al., 2023). Figure 14 illustrates the typical number of boardings at each bus station along the Metrobus route, providing insight into how people throughout Lahore utilise the system. High traffic at main transit stops in big cities reflects the desire for convenient and efficient travel options (Hafiz Usman Ahmed, 2014).

In addition to the MBS, the Lahore Orange Line Metro Train (OLMT) was launched in 2020 and operates as a fully automated 27.1 km rapid transit system between large urban areas (Shahid et al., 2020). The Lahore Orange Line Metro Train has the potential to replace at least 70,000 daily trips by car and motorbike. If so, the service could eliminate over 47,000 tons of CO_2 each year (Anam et al., 2025). Even so, challenges with electricity use and not integrating several modes slow down these benefits (Batool et al., 2020).

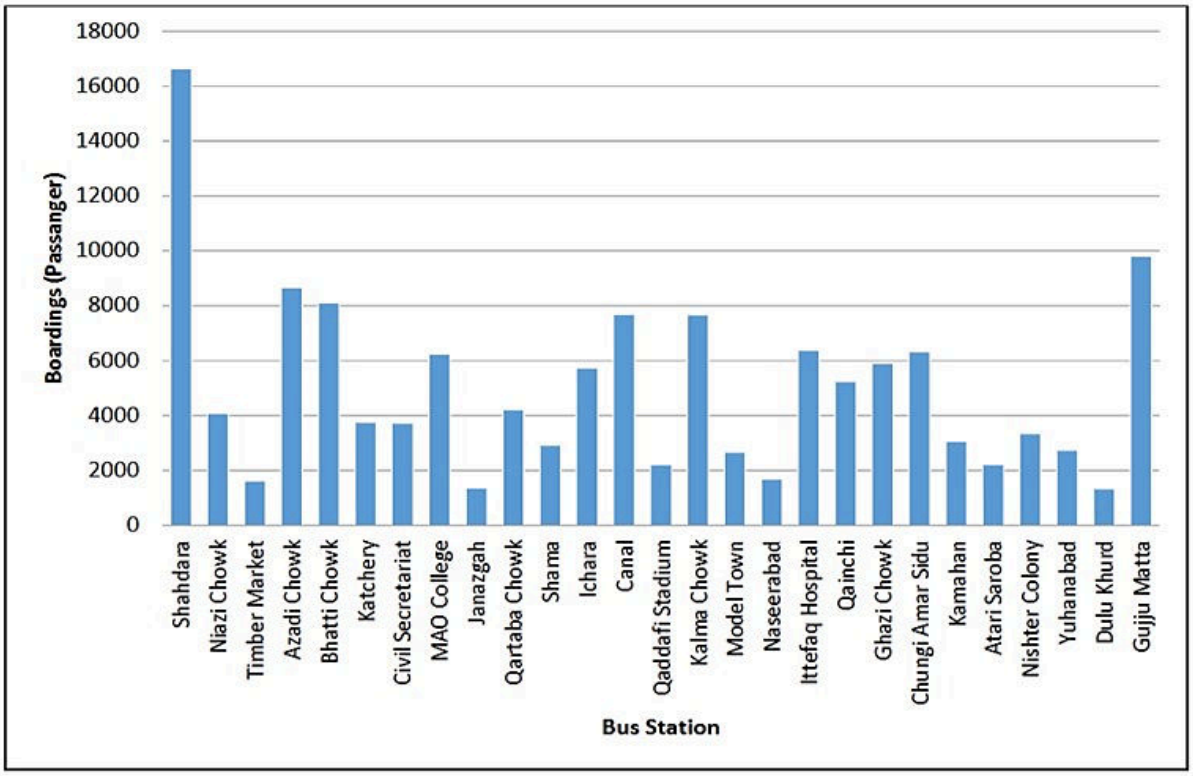

Figure 13. Average boardings at different stops of Metrobus Lahore.
Source: (Hafiz Usman Ahmed, 2014).

6.2. Islamabad – Rawalpindi Metro Bus:

The Islamabad-Rawalpindi Metrobus started operating in 2015, covering a 24 km BRT corridor (Saqib, Anwar, 2022). It was created to help locals find a cleaner way to travel, as the area has many high car owners (Shafqat, 2017). The Capital Development Authority's post-implementation evaluation discovered that the metrobus has resulted in a 22% decrease in vehicle kilometres travelled (VKT) along its route, which means approximately 19,000 tons of CO_2 are saved every year (Capital Development Authority, 2017). Although there have been advances, partial coverage and weak networks at the last mile have slowed the switch from private to public transport. Measures are being planned and implemented to improve these areas, including aligning with other local transport systems (Khan, 2017).

6.3. Peshawar Bus Rapid Transit (Zu Peshawar)

Launched as Zu Peshawar in 2020, Peshawar's BRT operates 27 km and uses hybrid diesel-electric buses (Zhang et al., 2025). Data from a case study by the Asian Development Bank (ADB) shows that the introduction of Zu Peshawar has led to a change in travel options for many, with more than 30% of users being former private vehicle users (Bank, 2022; Saleem et al., 2022). Thanks to cleaner vehicles and less congestion, the system is projected to cut GHG emissions by almost 62,000 tons of CO_2 every year (Arif, 2024). Thanks to its accessibility for all and the well-organised feeder network (Khan, 2020).

6.4. Karachi Green Line BRT

In November 2021, Karachi, the country's largest urban centre, launched the Green Line BRT. This project extends over 21 km and has a planned capacity of serving more than 135,000 passengers each day (Safdar et al., 2022). The Sindh Infrastructure Development Company Ltd (SIDCL) found that under current conditions, the Green Line has reduced car travel by 10%, with the potential for annual GHG savings of around 45,000 tons when ridership returns to normal (World Bank, 2023). Nevertheless, linking private vehicles to the informally run sector in Karachi and finishing the extension of certain lines are still preventing the best effects on the environment (Akber, 2024).

Table 5.
Summary of emissions reductions from urban transit projects in Pakistan

City	Project	Annual CO_2 Reduction (tons)	Modal Shift Impact	Reference
LAHORE	Metrobus	~31,000	15% reduction in private vehicle trips	(Iqbal et al., 2023)
LAHORE	Orange Line Metro Train	~47,000	~70,000 trips displaced per day	(Anam et al., 2025)
ISLAMABAD	Metrobus	~19,000	22% reduction in VKT	(Capital Development Authority, 2017)
PESHAWAR	Zu Peshawar BRT	~62,000	30% of riders shifted from private modes	(Arif, 2024)
KARACHI	Green Line BRT	~45,000 (projected)	10% reduction in private car use	(World Bank, 2023)

7. Discussion

Results from this review suggest that integrated technology-based strategies are essential to decreasing GHG emissions in the Pakistani transport sector. Switching to electric vehicles (EVs), compressed natural gas (CNG), and alternative fuels has become a promising strategy for reducing air pollution in cities where it is a major cause for worry (CDKN, 2023; Qadir,

2002; Qureshi, Lu, 2007). Even so, some problems are preventing wider use of these cars, such as a lack of charging spots for electricity and gas, not many refuelling stations for CNG and expensive initial costs (CPDI, 2023; Observatory, 2023). Integrating vehicle-to-grid V2G technology and smart grids works well to address these issues by supplying extra energy storage and helping regulate energy consumption (Kumar et al., 2024).

Policies, for example, tax breaks and subsidies for producers, along with incentives for individuals, help to encourage cleaner travel (ICCT, 2024; Ministry of Climate Change, 2019). Compared to other means, systems like Lahore's Metrobus reduce emissions by easing crowded roads and saving fuel (Qadir, 2002; Qureshi, Lu, 2007). Still, growing the public transport system is threatened by problems including a lack of funds, difficulties in government institutions and a lack of coordination with city planners (Ali et al., 2019; Bank, 2022).

Pakistan should work to broaden their public transport options, especially by adding a Bus rapid transit network, metro systems and encouraging more people to cycle and walk. Non - motorised transport NMT brings clear advantages, for example, there are no tailpipe emissions, the air is cleaner and public health is better (Ali et al., 2019; Qadir, 2002). Yet, there are challenges in expanding NMT because cities are crowded, and not much money is being spent on it. While CNG has been a smaller part of Pakistan's energy mix, it may not last for many years because of changing prices and scarce stations for refuelling (CDKN, 2023).

A transportation system can be made both sustainable and low in emissions if EVs are popularised, CNG infrastructure is improved, public transport jumps and NMT use increases. It will take the joint action of the government, local businesses and partners from abroad to get past these challenges. Higher awareness among people and research-relevant skills for employees are required to ensure that many use cleaner transportation technologies (CPDI, 2023; Tariq, Ali, 2017).

8. Conclusion

Solving the problem of increased transportation emissions in Pakistan will require many different methods. Rapid growth in cities, a rise in population and dependence on fossil fuels in transportation are the main reasons the country's transportation sector is a key source of greenhouse gas (GHG) emissions. Because of the sector's emissions, there is more global warming, plus higher risks to air quality, health and the environment. Pakistan needs to use a strategy that brings together advances in technology, new infrastructure and more environmentally conscious habits. Switches like the ones from petrol to EVs and CNG can greatly lower emissions in the transportation sector. Still, these new developments are not enough by themselves. Complementary work should include building sufficient EV charging infrastructure and improving public transportation.

Electric cars are a crucial choice that can reduce the emissions linked with personal automobiles. Even though the National Electric Vehicle Policy lays out a plan for more EV adoption, it won't work unless the government overcomes high launch costs, limited charging availability, and few people are aware of electric vehicles. Furthermore, CNG plays an important part since it provides a clean alternative to fossil fuels in the current situation. Although some cities use CNG to decrease vehicle emissions, Pakistan has to ensure that it is widely available and that the infrastructure is improved for everyone. Even though EVs and CNG vehicles will help shrink the sector's carbon footprint, they still depend on joint public measures and lengthy financial backing.

Building up public transportation is vital for encouraging people away from travel by public transportation and decreasing emissions. For example, Lahore Metrobus, Karachi Green Line and Lahore Orange Line help reduce traffic, make the air cleaner and reduce the amount of pollution. Although bringing these systems into urban mobility is great, there are still issues with funding, support from officials and expanding infrastructure. Encouraging walking and cycling (called NMT) can be done by making sidewalks wider and adding special lanes for cyclists. Using more of these alternatives helps reduce congestion and makes the environment better.

Transportation will become more sustainable and low-emission if people also change their behaviour. Campaigns that inform people are essential to help them see the benefits EVs, CNG and public transport offer both to the environment and the economy. The results of these initiatives will depend on cooperation between the public and the private sectors. Laws by the government should encourage energy-saving technologies, higher vehicle fuel economy and adopting clean ways of moving people and goods. Making transportation systems more resilient to climate change is very important. Pakistan should build its transportation systems to remain secure in times of shock from weather disasters and hurricanes. If infrastructure is built to survive climate change, it will keep traffic and transport running smoothly in the event of such changes.

To help create a sustainable transport system in Pakistan, several stakeholders, including the government, businesses and the public, must cooperate. Supporting EVs and sustainable transport requires policymakers to support their adoption, raise fuel standards and build more mass transit networks everywhere. We should also encourage international organisations and experts to help in securing both financing and the needed technology. Even though reaching a sustainable and strong transportation network in Pakistan is hard, it is possible to achieve. Putting together a sustainable manufacturing transportation system calls for future strategies, fresh ideas and reasonable spending on infrastructure for both the environment and the economy. In short, reducing emissions from transportation in Pakistan helps combat climate change, protect public health, build a stronger economy and improve quality of life for everyone. If Pakistan combines new technologies, enacts better policies and improves infrastructure, it can design a transportation network that lasts and can handle both climate change and the need for sustainable development.

References

1. Age, L.I., Anomaly, M.C. (2008). Global signatures and dynamical origins of the. *J. Clim*, *21*, 2283.
2. Ahmed, S., Huifang, W., Akhtar, S., Imran, S., Hassan, G., Wang, C. (2021). An analysis of urban sprawl in Pakistan: consequences, challenges, and the way forward. *International Journal of Agricultural Extension*, *8*(3), 257-278.
3. Ain, Q., Ullah, R., Kamran, M.A., Zulfiqar, F. (2021). Air pollution and its economic impacts at household level: Willingness to pay for environmental services in Pakistan. *Environmental Science and Pollution Research*, *28*(6), 6611-6618.
4. Akber, S. (2024). *Navigating Urban Transit Challenges in Emerging Economies: Insights From Karachi.* New York University Tandon School of Engineering.
5. Alfredo Rivera, S.M., Rutkowski, E. (November 26, 2024). *Global Greenhouse Gas Emissions:1990-2022 and Preliminary 2023 Estimates*. https://rhg.com/wp-content/uploads/2024/11/Global-Greenhouse-Gas-Emissions-1990-2022-and-2023-Estimates.pdf
6. Ali, R., Bakhsh, K., Yasin, M.A. (2019). Impact of urbanization on CO2 emissions in emerging economy: evidence from Pakistan. *Sustainable Cities and Society*, *48*, 101553.
7. Analytics, C. (2024). *Transport - 1.5°C national pathway explorer.*
8. Anam, M., Abdullah, M., Ur Rehman, Z. (2025). Rider Perception and Usage Intention for Pakistan's First Rail Mass Transit: A Study of Lahore's Orange Line Metro. *Transportation in Developing Economies*, *11*(1), 1-16.
9. Anenberg, S.C., Miller, J., Minjares, R., Du, L., Henze, D.K., Lacey, F., Malley, C.S., Emberson, L., Franco, V., Klimont, Z. (2017). Impacts and mitigation of excess diesel-related NO x emissions in 11 major vehicle markets. *Nature*, *545*(7655), 467-471.
10. Arif, J. (2024). Environmental Impact of Bus Rapid Transit (BRT) in Peshawar, Pakistan Bussi kiirraudtee (BRT) keskkonnamõju Peshawaris, Pakistanis.
11. Arif, M.M., Ahmad, S.R., Abubakar, M. (2023). Impacts of air pollution on human health in Lahore city, Pakistan: A review. *Global Research Journal of Natural Science and Technology*, *1*(2), 39-48.
12. Asim, M., Usman, M., Abbasi, M.S., Ahmad, S., Mujtaba, M., Soudagar, M.E.M., Mohamed, A. (2022). Estimating the long-term effects of national and international sustainable transport policies on energy consumption and emissions of road transport sector of Pakistan. *Sustainability*, *14*(9), 5732.
13. Aziz, R. (2015). Evaluation of Lahore bus rapid transit based on key performance indicators. *Pakistan Journal of Science*, *67*(1).
14. Azmat, M. (2015). Water Resources Availability and Hydropower Production under Current and Future Climate Scenarios: The Case of Jhelum River Basin, Pakistan.

15. Bajwa, A.U., Sheikh, H.A. (2023). Contribution of road transport to Pakistan's air pollution in the urban environment. *Air*, *1*(4), 237-257.
16. Bank, A.D. (2022). *Climate Change Adaptation in Transport Infrastructure.* Asian Development Bank.
17. Bank, W. (2022). *Pakistan Urban Transport and Air Quality Report*.
18. Bank, W. (2022). *United Nations Population Division, Urban population (% of total population) - Pakistan,* https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=PK
19. Bank, W. (2023). *Climate and Health Vulnerability Assessment: Pakistan.* https://documents1.worldbank.org/curated/en/099070324142031034/pdf/P50199317ac51302718f4d1733583b5c276.pdf
20. Batool, I., Irshad, M., Abid, M. (2020). A Policy Move towards Sustainable Urban Transport in Pakistan: Measuring the Social, Environmental and Economic Impacts of Lahore BRT System.
21. Capital Development Authority (2017). *Post-Evaluation Report: Islamabad Metrobus*. Retrieved from: https://cdia.asia/wp-content/uploads/2021/11/Islamabad-v3.pdf?utm
22. CDKN (2023). *Greenhouse Gas Mitigation Options for Pakistan: Transport Sector. Climate and Development Knowledge Network*.
23. Change, I.C. (2022). *Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*.
24. CPDI (2023). *Policy Brief: Electric Vehicles in Pakistan.*
25. Creutzig, F., Jochem, P., Edelenbosch, O.Y., Mattauch, L., van Vuuren, D.P., McCollum, D., Minx, J., Riahi, K., Rose, S. (2015). Transport: A roadblock to climate change mitigation. *Science*, 911-912.
26. Dai, A. (2013). Increasing drought under global warming in observations and models. *Nature climate change*, *3*(1), 52-58.
27. Emanuel, K. (2017). Assessing the present and future probability of Hurricane Harvey's rainfall. *Proceedings of the national academy of sciences*, *114*(48), 12681-12684.
28. FAO (2018). *The State of Food Security and Nutrition in the World 2018.*
29. Farooq, M.S., Uzair, M., Raza, A., Habib, M., Xu, Y., Yousuf, M., Yang, S.H., Ramzan Khan, M. (2022). Uncovering the research gaps to alleviate the negative impacts of climate change on food security: a review. *Frontiers in plant science*, *13*, 927535.
30. Hafiz Usman Ahmed, A.A. (2014). Evaluation of System Performance of Metro Bus Lahore. https://doi.org/DOI: 10.13140/RG.2.2.11588.83840
31. Hansen, J., Ruedy, R., Sato, M., Lo, K. (2010). Global surface temperature change. *Reviews of geophysics*, *48*(4).
32. Haq, R. (2019). *Brief Overview of Pakistan's Electric Vehicle Policy*.
33. Herath Bandara, S.J., Thilakarathne, N. (2025). Economic and public health impacts of transportation-driven air pollution in South Asia. *Sustainability*, *17*(5), 2306.

34. Hyder, A.H.A., Awad, J., Jung, C., Sher, B.K. (2024). Enhancing climate resilience against flooding in housing design through synergistic strategies in Pakistan. *Future Cities and Environment*, *10*(1).
35. ICCT, T. (2024). *Pakistan's National Electric Vehicle Policy: Charging towards the future*. International Council on Clean Transportation, 15 January.
36. IEA (2023). *CO2 Emissions from Fuel Combustion 2023*.
37. Ilyas, S.Z. (2007). A review of transport and urban air pollution in Pakistan. *Journal of Applied Sciences and Environmental Management*, *11*(2).
38. Ilyas, S.Z., Khattak, A.I., Nasir, S., Qurashi, T., Durrani, R. (2010). Air pollution assessment in urban areas and its impact on human health in the city of Quetta, Pakistan. *Clean Technologies and Environmental Policy*, *12*, 291-299.
39. Imran, M. (2010). Sustainable urban transport in Pakistan: an institutional analysis. *International Planning Studies*, *15*(2), 119-141.
40. Imran, W., Shutsha, K.E. (2024). *Is Pakistan On The Brink Of A Green Transport Revolution, Or Are Its Efforts Lagging Behind The World's Leaders In Sustainable Travel, Leaving A Larger Carbon Footprint In Its Wake?*
41. Iqbal, M.P. (2020). Effect of climate change on health in Pakistan: climate change and health in Pakistan. *Proceedings of the Pakistan Academy of Sciences: B. Life and Environmental Sciences*, *57*(3), 1-12.
42. Iqbal, R., Ullah, M.U., Habib, G., Ullah, M.K. (2023). Evaluating Public and Private Transport of Lahore. *Journal of World Science*, *2*(2), 243-254.
43. Iqbal, S., Khan, H.A., Ullah, I., Khan, M.W., Hussain, S. (2024). Understanding the pavement project failures in Pakistan: identifying causes and solutions. *Natural and Applied Sciences International Journal (NASIJ)*, *5*(1), 55-74.
44. Khan, H.O.A., Saeed, F., Arshad, N. (2021). Propelling the Penetration of Electric Vehicles in Pakistan by Optimal Placement of Charging Stations. *Engineering Proceedings*, *11*(1), 34.
45. Khan, M.A. (2017). Urban Transportation Issues of the Poor in South AsiaCase Study: Islamabad, Pakistan.
46. Khan, M.A., Khan, J.A., Ali, Z., Ahmad, I., Ahmad, M.N. (2016). The challenge of climate change and policy response in Pakistan. *Environmental Earth Sciences*, *75*, 1-16.
47. Khan, M.A.M. (2020). *Infrastructure development and public-private partnership: Measuring impacts of urban transport infrastructure in Pakistan*.
48. Khan, M.R., Aziz, S., Rashid, R.M., Baig, A.U. (2023). Overview of Pakistan's Transportation Infrastructure from Future Perspective: A Systematic Literature Review. *Journal of Applied Research and Multidisciplinary Studies*, 2-26.
49. Khan, M.S., Jamil, K.,Malik, A. A. (2022). Delivering Urban Mass Transit—The Case of Lahore, Pakistan.

50. Khan, W.A., Shah, S.A., Khan, A. (2022). In Pakistan, the Transport and Urban Air Pollution Impacts on Human Health and Practical Steps to Avoid Them: A Review. *Journal of International Cooperation and Development*, *5*.
51. Kumar, R., Kanwal, A., Asim, M., Pervez, M., Mujtaba, M., Fouad, Y., Kalam, M. (2024). Transforming the transportation sector: Mitigating greenhouse gas emissions through electric vehicles (EVs) and exploring sustainable pathways. *AIP Advances*, *14*(3).
52. Landsberg, H.E. (1970). Man-made climatic changes: man's activities have altered the climate of urbanized areas and may affect global climate in the future. *Science*, *170*(3964), 1265-1274.
53. Lobell, D.B., Schlenker, W., Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. *Science*, *333*(6042), 616-620.
54. Metrohub (2024). *Islamabad Metro Bus Map July 2024 Updated*. https://commons.wikimedia.org/w/index.php?curid=150347747.
55. Ministry of Climate Change (2019). *Government of Pakistan (2019) National Electric Vehicle Policy.*
56. Nadeem, A., Rossi, M., Corradi, E., Jin, L., Comodi, G., Sheikh, N.A. (2022). Energy-environmental planning of electric vehicles (EVs): A case study of the national energy system of Pakistan. *Energies*, *15*(9), 3054.
57. Nafees, M., Bacha, M.S., Muhammad, M., Khurshid, M., Nawab, A., Ahmad, F. (2024). *Climate Change Impacts, Causes, mitigation and adaptation*.
58. News, D. (2025). *Bike lanes are being constructed on Ferozepur Road and Canal Road.* https://dunyanews.tv/en/Pakistan/863309-separate-lanes-for-cyclists-motorcyclists-designated-on-lahore-roads
59. Nicholls, R.J., Hoozemans, F.M., Marchand, M. (1999). Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses. *Global Environmental Change*, *9*, S69-S87.
60. Observatory, A.T. (2023). *Transport and Climate Profile.*
61. OECD/ITF (2018). *Transport CO2 and the Paris Climate Agreement*.
62. Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., Brennan, S.E. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*, *372*.
63. Parekh, P.P., Khwaja, H.A., Khan, A.R., Naqvi, R.R., Malik, A., Shah, S.A., Khan, K., Hussain, G. (2001). Ambient air quality of two metropolitan cities of Pakistan and its health implications. *Atmospheric Environment*, *35*(34), 5971-5978.
64. Partnership, N. (2021). *Transport and Climate Change: How Nationally Determined Contributions Can Accelerate Transport Decarbonization.* https://ndcpartnership.org/transport-and-climate-change-how-nationally-determined-contributions-can-accelerate-transport

65. Qadir, N.F. (2002). Air quality management in Pakistani cities: Trends and challenges. *Better Air Quality in Asian and Pacific Rim Cities*, 16-18.
66. Qin, Y., Zhang, X., Tan, K., Wang, J. (2022). A review on the influencing factors of pavement surface temperature. *Environmental Science and Pollution Research*, *29*(45), 67659-67674.
67. Qureshi, I.A., Lu, H. (2007). Urban transport and sustainable transport strategies: A case study of Karachi, Pakistan. *Tsinghua science and technology*, *12*(3), 309-317.
68. Rathore, K., Ali, K. (2015). Evaluation of Lahore Bus Rapid Transit System. *International Journal of Management Sciences and Business Research*, *4*(10).
69. Regmi, M.B., Hanaoka, S. (2009). Impacts of climate change on transport and adaptation in Asia. *Proceedings of the Eastern Asia Society for Transportation Studies, Vol. 7* (The 8th International Conference of Eastern Asia Society for Transportation Studies).
70. Safdar, M., Jamal, A., Al-Ahmadi, H.M., Rahman, M.T., Almoshaogeh, M. (2022). Analysis of the influential factors towards adoption of car-sharing: A case study of a megacity in a developing country. *Sustainability*, *14*(5), 2778.
71. Sajjad, S., Shirazi, S.A., Ahmed Khan, M., Raza, A. (2009). Urbanization effects on temperature trends of Lahore during 1950-2007. *International Journal of Climate Change Strategies and Management*, *1*(3), 274-281.
72. Saleem, M.A., Murtaza, G., Ali, R.A., Qadri, S.U. (2022). Sustainability Strategies for Urban Mass Transit—Case of Pakistan. In: *Environmental Sustainability in Emerging Markets: Consumer, Organisation and Policy Perspectives* (pp. 197-212). Springer.
73. Saqib, A., Anwar, M.A. (2022). Cost benefit analysis of Pakistan metro bus system (Rawalpindi-Islamabad). *Economics*.
74. Sarfraz, Z. (2020). The social and economic burden of smog in Pakistan. *Pakistan Journal of Surgery and Medicine*, *1*(1), 5-7.
75. Shafqat, M.W.A. (2017). *Benefits of the metro bus service (MBS) in Rawalpindi/Islamabad.* Pakistan Institute of Development Economics.
76. Shah, S.M.H., Mustaffa, Z., Teo, F.Y., Imam, M.A.H., Yusof, K.W., Al-Qadami, E.H.H. (2020). A review of the flood hazard and risk management in the South Asian Region, particularly Pakistan. *Scientific African*, *10*, e00651.
77. Shahid, A., Ansub, M., Hafeez, A., Saleem, H., Basharat, A. (2020). Socio-economic impacts of transit projects (a case study of orange line Lahore). *Saudi J. Civ. Eng*, *4*, 161-169.
78. Sims, R., Schaeffer, R., Creutzig, F., Cruz-Núñez, X., D'Agosto, M., Dimitriu, D., Figueroa Meza, M.J., Fulton, L., Kobayashi, S., Lah, O., McKinnon, A., Newman, P., Schauer, J.J., Sperling, D., Tiwari, G. (2014). Transport. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *Cambridge University Press*, 599-670. https://doi.org/10.1017/CBO9781107415416.005

79. Solomon, S., Plattner, G.-K., Knutti, R., Friedlingstein, P. (2009). Irreversible climate change due to carbon dioxide emissions. *Proceedings of the national academy of sciences*, *106*(6), 1704-1709.
80. Stern, N. (2008). The economics of climate change. *American Economic Review*, *98*(2), 1-37.
81. Tariq, S., Ali, M. (2017). Spatiotemporal assessment of CO2 emissions and its satellite remote sensing over Pakistan and neighboring regions. *Journal of Atmospheric and Solar-Terrestrial Physics*, *152*, 11-19.
82. Transparency, C. (2020). *Pakistan Climate Transparency Report.*
83. Transport, C. (2023). *5 years Paris Agreement - 5 years of Action in Transport*. C. Transport.
84. UN-Habitat (2023). *Pakistan Country Report 2023.* https://documents1.worldbank.org/curated/en/099070324142031034/pdf/P50199317ac51302718f4d1733583b5c276.pdf
85. UNFCCC (2015). *United Nations Framework Convention on Climate Change*. u. n. c. change.
86. UNFCCC (2021). *National Adaptation Plan - Pakistan.* https://unfccc.int/sites/default/files/resource/National_Adaptation_Plan_Pakistan.pdf
87. Unit., U. (2024). *Transforming the Transportation Sector Report (2024) Electric Vehicle Infrastructure and Policy in Pakistan*.
88. Walsh, K.J., McBride, J.L., Klotzbach, P.J., Balachandran, S., Camargo, S.J., Holland, G., Knutson, T.R., Kossin, J.P., Lee, T.C., Sobel, A. (2016). Tropical cyclones and climate change. *Wiley Interdisciplinary Reviews: Climate Change*, *7*(1), 65-89.
89. Wheeler, T., Von Braun, J. (2013). Climate change impacts on global food security. *Science*, *341*(6145), 508-513.
90. WHO (2018). *Ambient (outdoor) air pollution. World Health Organization*. https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health, 21 May 2025.
91. WHO (2023). *Air pollution and health in Pakistan*. https://www.who.int/pakistan/news/detail/2023/air-pollution-and-health
92. World Bank (2023). *Transport Decarbonization in Megacities: Karachi. Policy Brief*. https://documents1.worldbank.org/curated/en/099062723022039399/pdf/P166732061aa420c10a3bc00585b20fe582.pdf
93. Wuebbles, D.J., Fahey, D.W., Hibbard, K.A., Arnold, J.R., DeAngelo, B., Doherty, S., Easterling, D.R., Edmonds, J., Edmonds, T., Hall, T. (2017). *Climate science special report: Fourth national climate assessment (NCA4), Volume I*.
94. Yaoxian Huang, N.U., Harper, K., Heyes, C. (2020). Global Climate and Human Health Effects of theGasoline and Diesel Vehicle Fleets. *AGu advancing earth and space scinence*, *4*(3), 13. https://doi.org/10.1029/2019GH000240

95. Yasar, A., Haider, R., Tabinda, A.B., Kausar, F., Khan, M. (2013). A comparison of engine emissions from heavy, medium, and light vehicles for CNG, diesel, and gasoline fuels. *Pol. J. Environ. Stud*, *22*(4), 1277-1281.
96. Zeeshan, M., Iqbal, N. (2022). Sustainable Solutions to Climate Challenges: The Role of Innovation in Pakistan. *Journal of Energy and Environmental Policy Options*, *5*(2), 39-45.
97. Zhang, H., Ray, M., Shin, J. (2025). *How Cities Are Placing People at the Center of Urban Mobility Transformations*.

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THE POTENTIAL OF ARTIFICIAL INTELLIGENCE IN INNOVATION MANAGEMENT AS A CATALYST FOR FLOW IN DIVERGENT THINKING AND EUDAIMONIA

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Purpose: The purpose of this article is to explore the potential of Artificial Intelligence (AI) to support innovation management processes by stimulating creative thinking - particularly divergent thinking - and by fostering conditions conducive to achieving flow states, autotelic motivation, and deep psychological well-being (eudaimonia).
Design/methodology/approach: This is a qualitative, exploratory-theoretical study, enriched with elements of conceptual modeling. The empirical analysis is based on the author's subjective experiences and observations.
Findings: The study demonstrates that appropriately designed AI can effectively support flow states, divergent thinking, and eudaimonia, serving as a creative catalyst for innovation.
Research limitations/implications: The main limitations involve the availability of technological solutions and the reliance on theoretical analysis and the author's subjective perspective. These limitations highlight the need for further, in-depth research incorporating neuroimaging methods and long-term studies on AI's impact on creativity and well-being.
Practical implications: The findings suggest that integrating AI as a tool for supporting flow and creativity can significantly enhance innovation, employee engagement, and well-being. This, in turn, translates into increased effectiveness of innovative teams, improved motivation and satisfaction, and greater organizational value and competitiveness.
Social implications: The study emphasizes AI's potential to foster creativity, a sense of meaning, and well-being, which may contribute to the development of more human-centered technologies, the promotion of positive attitudes towards AI, and the inspiration for public policies and CSR strategies focused on quality of life, emotional education, and sustainable social development.
Originality/value: The article presents an original perspective on AI as a catalyst for flow, divergent thinking, and eudaimonia. It integrates innovation management with neuroscience, making it a valuable resource for researchers, AI designers, and innovation leaders.
Keywords: Human-centered AI, creativity, stimulating dissipative structures, intrinsic motivation, well-being.
Category of the paper: Research on innovation management.

1. Introduction

The world of innovation is continuously redefining the boundaries of technological, organizational, and cognitive possibilities. Within this evolving landscape, Artificial Intelligence (AI) is emerging as a transformative force - not only enhancing decision-making processes but also co-creating spaces for creativity, reflection, and experimentation. Contemporary innovation management must recognize the human creative factor, which is increasingly shaped by interaction with intelligent systems. This raises an important question: how can AI influence the quality of human creative work - can it replace it, or should it rather become a tool that facilitates flow (Csikszentmihalyi, 1996) and inner fulfillment?

This article represents an interdisciplinary synthesis, merging perspectives from innovation management, neuropsychology, and the philosophy of well-being to highlight AI's potential as a catalyst for flow, an activator of divergent thinking, and a supporter of eudaimonia. Eudaimonia is understood here as a lasting, meaningful, and profound sense of fulfillment (Porczyńska-Ciszewska, 2013). Central to this exploration are also the concepts of the autotelic personality, brain structures involved in creativity, and the neuropsychological aspects of intrinsic motivation, engagement, and workplace happiness (Matacz et al., 2022). At the same time, the article critically reflects on the paradox of AI: while it can support creativity and well-being, poorly managed, it may also erode them. By analyzing both the opportunities and threats associated with AI in creative and organizational environments, the article proposes a framework for the ethical and conscious use of new technologies in the service of humanity.

2. Literature Review

Contemporary approaches to innovation are increasingly moving away from a linear "idea-to-implementation" model towards more complex, nonlinear, and iterative frameworks based on exploration, experimentation, and the ability to generate original and useful solutions (Czerwińska-Lubszczyk et al., 2022). Creativity is no longer just the initial stage of innovation - it becomes a continuous component, present at every stage from ideation and research to market implementation. Innovation is not the sole domain of R&D departments but involves the entire organization. Organizational culture, structure, and management should foster creative thinking, interdisciplinary collaboration (Knefel, 2018), and experimentation. Creativity is becoming a universal competence rather than an elite skill.

Research into innovation-supporting environments identifies several key factors for fostering creativity and flow (Czerwińska-Lubszczyk et al., 2022; Gajdzik et al., 2022), including autonomy, cognitive challenge, collaboration and trust (psychological safety), access

to resources (time, tools, knowledge - including AI), and tolerance for failure and experimentation. Organizations cultivating these principles are more likely to develop bottom-up innovations and knowledge cross-pollination (Plucker, Makel, 2010; Ryff, Singer, 2004). Employee creativity should be viewed as a strategic organizational asset, and leaders play a crucial role as facilitators of creative processes (Wyrzykowska, 2020; Ziębicki, 2020; Nitsch et al., 2024; Balicki, Leja, 2025).

The concept of flow refers to a state of deep engagement and concentration, where time seems to vanish and individuals experience satisfaction, enhanced performance, and intrinsic motivation (Csikszentmihalyi, 1990). In creative work, flow merges high productivity with a profound sense of fulfillment. Key conditions for achieving flow include clear goals, immediate feedback, appropriate challenge levels (balance between skill and difficulty), a sense of control and autonomy, deep concentration, and the merging of action and awareness. Flow fosters divergent thinking, innovative ideas, and cognitive risk-taking. Environments that enable flow tend to show higher satisfaction and engagement levels. Flow can be individual or collective (team-based flow) (Matacz et al., 2022).

Not everyone easily achieves flow. A pivotal factor is the autotelic personality - individuals who derive intrinsic satisfaction from the activity itself (Porczyńska-Ciszewska, 2013). Autotelic individuals are characterized by high intrinsic motivation, cognitive openness, a tendency toward exploration, independence, and the ability to concentrate. They are predisposed to engage in creative processes and experience eudaimonia through work. Neuropsychologically, flow is associated with altered brain function and temporary hypofrontality (Csikszentmihalyi, 1990). Creative thinking involves dissipative structures that enable the reorganization of knowledge and the association of ideas (Grygiel, 2015).

Divergent thinking involves generating multiple possible answers to open-ended problems, activating creativity, flexibility, and originality (Będkowski et al., 2022). Its key features include fluency (number of ideas), flexibility (variety), originality (uniqueness), and elaboration (depth). In innovation management, it is essential in the exploratory phase, enabling alternative concepts and breaking cognitive patterns. It supports design thinking, brainstorming, foresight, and breakthrough innovation. Divergent thinking is fostered by openness to experience, psychological safety, intrinsic motivation (especially in autotelic individuals), and flow states. It can be inhibited by time pressure, hierarchical cultures, and conformity. It activates the brain’s Default Mode Network (DMN), and its simultaneous interaction with other networks enables the formation of new meaning structures through associative thinking (Radoń, 2018).

AI can support these processes by suggesting non-obvious associations (data analysis), inspiring alternative perspectives, and providing personalized cognitive assistance. Rather than replacing thought, AI can expand it. Applications include generative language models, knowledge-recombining recommendation systems, simulations, and predictive models. However, a paradox exists: AI can either stimulate or suppress creativity, depending on whether it is used in a controlling or empowering manner. Divergent thinking, when supported by the

right culture and technology like AI, can lead to breakthrough ideas, deeper flow states, and fulfillment. AI can act as a catalyst for flow and divergent thinking - provided there is a balance between structure and freedom to enhance, not replace, human imagination.

3. Methodology

The study is qualitative and exploratory-theoretical in nature. Its aim is to provide a conceptual analysis of the potential of AI in relation to psychological constructs such as flow, divergent thinking, and eudaimonia within the specific domain of innovation management. The research method is based on interdisciplinary synthesis, combining perspectives from innovation management, neuropsychology, and the philosophy of well-being.

The rationale for this methodology lies in the exploratory character of the research, which seeks to reveal new relationships between disciplines. Given the emerging nature of AI and its largely unexplored interactions with complex cognitive and emotional human processes in creative work environments, a theoretical and exploratory approach allows for the formulation of novel hypotheses and the development of conceptual frameworks for future empirical research.

The study incorporates elements of conceptual modeling, aiming to organize and present the relationships among the constructs analyzed (AI, flow, divergent thinking, eudaimonia, innovation management) in a coherent theoretical model suggesting their interactions and mutual influence.

It is important to note that this is a conceptual study. The analysis of AI’s potential is based on theoretical premises and the author's subjective insights. This approach is justified by the innovative and exploratory character of the research, which requires preliminary theoretical synthesis before empirical validation.

4. Results

The primary hypothesis explored in this study was: Artificial Intelligence (AI) has significant potential to support innovation management processes by stimulating divergent creative thinking, catalyzing flow states, and fostering deep psychological well-being (eudaimonia) among employees.

The results of the theoretical analysis and conceptual modeling support this hypothesis. A review of literature from innovation management, neuropsychology, and positive psychology reveals that AI possesses inherent capabilities which, when consciously directed, can support

conditions necessary for achieving flow - human-centered AI, e.g., through reducing cognitive barriers, enhancing feedback, personalizing challenges, and stimulating inspiration (Nitsch et al., 2024). Furthermore, AI's ability to suggest non-obvious associations, generate alternative perspectives, and provoke the questioning of assumptions was identified as a key factor supporting divergent thinking and activating relevant neural networks. Finally, AI's capacity to support competence, stimulate development, and affirm meaning in work was recognized as a contributor to the experience of eudaimonia (Figure 1).

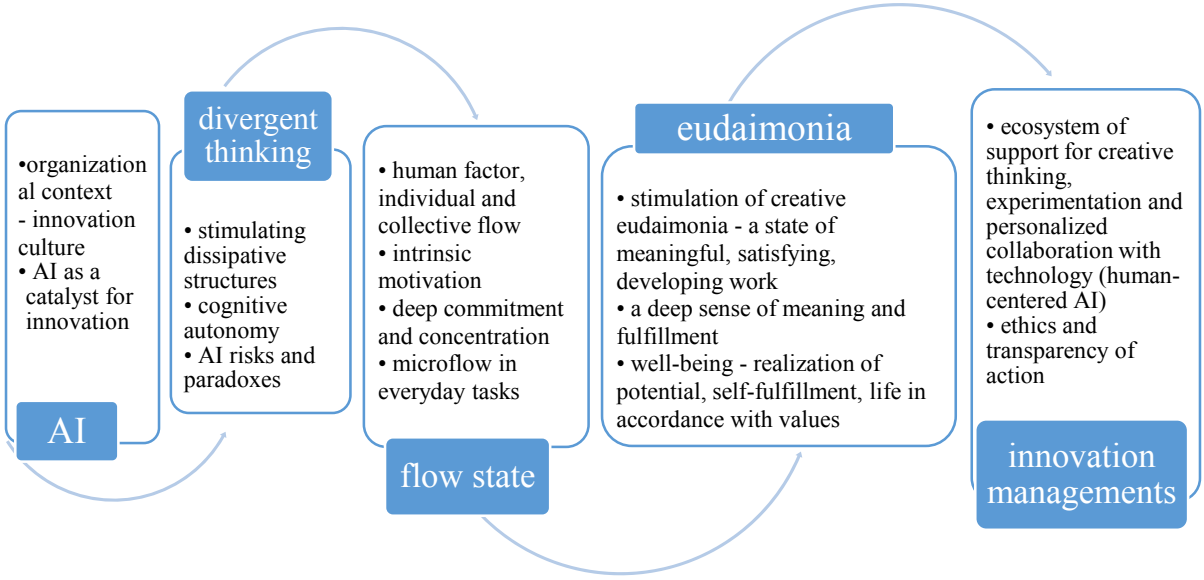

Figure 1. AI Model as a Catalyst for Flow, Divergent Thinking, and Eudaimonia.
Source: Author's own elaboration.

The theoretical and model-based findings suggest that AI can function as an accelerator of creativity and well-being, confirming the research hypothesis. However, full empirical verification of these relationships will require further studies, including neuroimaging research.

5. Discussion

The results - based on qualitative analysis and conceptual modeling - indicate that Artificial Intelligence can be a powerful tool in supporting human creativity, flow states, and eudaimonia, and thereby, innovation management. The study shows that well-designed AI can play a crucial role as a catalyst for human creativity, engagement, and well-being in innovation processes.

This potential lies in AI's capacity to reduce cognitive barriers, enhance feedback, personalize challenges, and stimulate inspiration. This observation is particularly relevant in the digital age, where organizational innovation depends not only on technology but increasingly on the ability to mobilize and support human creative potential.

This research shifts the perspective on AI in innovation management - from being merely an efficiency tool to a potential partner in the creative process, capable of influencing deep psychological states that foster innovation, such as flow, divergent thinking, and eudaimonia.

In terms of divergent thinking, the analysis emphasizes AI's role in suggesting non-obvious connections, inspiring alternative viewpoints, and provoking the reevaluation of assumptions and the redefinition of problems - aligning with the concept of AI as a tool for augmented cognition. It was found that AI can stimulate neural structures responsible for creative thinking - such as dissipative networks and the DMN - by providing novel stimuli and perspectives. This represents a novel insight, integrating technological and neuropsychological perspectives and pointing directly to potential mechanisms through which AI influences creative processes.

Other researchers have already highlighted the significance of flow, divergent thinking, and eudaimonia for innovation (Csikszentmihalyi, 1990; Porczyńska-Ciszewska, 2013; Będkowski et al., 2022). It has also been recognized that environmental factors such as autonomy, challenge, trust, and access to resources (including digital ones) foster these states. The present study contributes to this body of knowledge by offering a conceptual framework that demonstrates how intentional design of interactions with AI can activate these psychological states and processes, thereby becoming a catalyst for creativity. This research introduces novelty by identifying specific ways in which Artificial Intelligence can function as a catalyst for these phenomena - moving beyond the generic notion that technology is merely a resource.

The existing literature has lacked a coherent, interdisciplinary model illustrating how AI can intentionally support these uniquely human aspects of the creative process and well-being. It has been shown that AI is not merely a tool but can become a "co-author" of ideas and a supportive partner - provided that the interaction is properly designed.

Ethical frameworks for Artificial Intelligence in creative work should be grounded in the principles of transparency (understanding how AI operates), co-creativity (AI as a partner, not a dictator), adaptability (responsiveness to user needs), and eudaimonic stimulation (supporting the pursuit of meaning and fulfillment, not merely efficiency). AI should not "program" happiness or instrumentalize human emotions and motivation, but rather serve human agency and development - creating spaces where individuals can discover for themselves what brings them fulfillment. This aligns with the principles of human-centered innovation and human-centered AI workplaces, which form both an ethical imperative and a practical developmental direction.

Of particular importance is recognizing the risks associated with algorithmic nudging and cognitive manipulation. If AI takes over the creative process, diminishes users' sense of agency, or limits exploration, it may lead to reduced intrinsic motivation (especially when tasks become too easy), lower user engagement, and a loss of meaningfulness in work.

The critical analysis of AI highlights a number of limitations and weaknesses, identified as cognitive-motivational paradoxes: namely, that AI - while capable of supporting well-being - can also contribute to its erosion. There is a tension between automation and autonomy,

efficiency and meaning, personalization and exploration restriction, as well as support and dependency. These insights are essential, as they demonstrate that not every AI implementation will be beneficial to human creativity and well-being.

Another important outcome of the analysis is the formulation of conceptual frameworks for designing human - AI interaction in the workplace. These frameworks aim not only to enhance productivity but also to deepen employee engagement, satisfaction, and well-being - including eudaimonia. Translating the constructs of flow and autotelic personality into measurable organizational indicators enables the proposal of new KPIs. For example, instead of focusing solely on the number of ideas generated, organizations could measure subjective satisfaction and sense of meaning among employees using AI, the frequency of experiencing flow, (e.g., via pulse check surveys or self-assessment questionnaires), and the quality of AI use in creative processes-evaluating whether technology supports autonomy and deep engagement or merely automates and dilutes the process.

States such as a sense of meaning, autonomy, personal growth, and high competence levels can be measured using psychometric tools. In the context of talent development strategies, these findings suggest the need to identify and support individuals with autotelic traits and to design working conditions conducive to frequent experiences of flow, e.g., through tasks with clear goals and immediate feedback, which can be facilitated by adaptive AI systems. Thus, AI may enhance competence through constructive feedback, stimulate growth by offering new challenges, and even affirm meaning through participation in socially valuable projects - aligning with a eudaimonic understanding of happiness as the realization of human potential and living in accordance with one’s values.

Ethical frameworks for AI in creative work should remain rooted in transparency, co-creativity, adaptability, and the pursuit of eudaimonia. AI should not attempt to "program" happiness or exploit emotional and motivational processes, but rather support human agency and flourishing. Human-centered innovation and human-centered AI workplaces represent both ethical and practical paths forward. Innovation team leaders must ensure a balance between technological support and human agency while cultivating emotional intelligence in the context of AI collaboration.

The results of this study support the hypothesis that Artificial Intelligence has the potential to act as a catalyst for flow, divergent thinking, and eudaimonia in the context of innovation management, and they offer theoretical mechanisms to explain this impact. Future research should focus on empirically verifying these relationships, including through neuroimaging techniques and long-term observational studies. Further investigation is also needed into the specific AI algorithms and models that best support flow in individuals with different personality types, as well as how AI influences the development of autotelic personality traits and metacognitive competencies. Equally important is research on designing organizational cultures that support flow in collaboration with AI while preserving humanistic values (Szmidt, 2017).

In conclusion, this study provides theoretical and conceptual foundations for the design of innovative, human-centered AI work environments. The insights gained may inform the development of new organizational models, talent management strategies, and guidelines for the ethical design of AI systems that support creativity and well-being.

6. Conclusions

The conclusions drawn from this qualitative, exploratory-theoretical study involving conceptual modeling clearly indicate that Artificial Intelligence holds significant potential to serve as a catalyst in processes that support human creativity, flow states, and eudaimonia within innovation management.

The theoretical implications of these findings lie in the integration of perspectives from innovation management, neuropsychology, and positive psychology, thereby establishing a new framework for understanding the role of technology in stimulating human creative potential. The study proposes a conceptual model in which AI does not replace but rather augments human cognitive capabilities, facilitating the conditions necessary for achieving flow and activating mechanisms of divergent thinking. It also underscores the importance of the autotelic personality and intrinsic motivation as foundational elements for innovation and sustained engagement.

The practical implications are wide-ranging. The findings suggest that when Artificial Intelligence is designed and implemented through a human-centered AI approach, it can become a valuable tool for organizations. AI can contribute to increased innovation, employee engagement, and well-being, leading to improved team performance and greater competitiveness. This implies a need to rethink talent management strategies, to design work environments that foster flow (e.g., through task personalization and real-time feedback supported by AI), and to develop new KPI metrics that go beyond traditional efficiency measures by incorporating subjective satisfaction, a sense of meaning, and the quality of flow experiences.

Equally important is the training of leaders to understand both the potential and the limitations of AI in the context of human psychology, and to foster a culture grounded in trust and autonomy - essential for creative collaboration with technology. Artificial Intelligence should serve human agency and development, rather than facilitate instrumentalization or replacement.

The conclusions of this analysis emphasize that innovation management in the era of AI requires a deeper understanding of the human mind, motivation, and creative flow. This necessitates a shift away from purely technological or procedural approaches toward the construction of a creative ecosystem, where technology coexists with human capabilities and

organizational culture (Raport FDP, 2020). AI can indeed support these positive phenomena, but only if system design and usage are intentional, ethical, and oriented toward strengthening human autonomy and intrinsic motivation - rather than algorithmic nudging or cognitive manipulation. The full realization of this potential demands continued interdisciplinary research.

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References

1. Balicki, T., Leja., K. (2025) *Bezpieczeństwo psychologiczne jako warunek rozwoju mikroprzedsiębiorstwa.* WSGE University of Applied Sciences in Józefów https://www.jomswsge.com/pdf-202554-124340?filename=Psychological%20Safety%20as%20a.pdf
2. Będkowski, M. et al. (2022). *Sztuczna inteligencja (AI) jako megatrend kształtujący edukację Jak przygotowywać się na szanse i wyzwania społeczno-gospodarcze związane ze sztuczną inteligencją*? Instytut Badań Edukacyjnych.
3. Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*. New York: Harper & Row.
4. Csikszentmihalyi, M. (1996). *Creativity: Flow and the psychology of discovery and invention*. New York: Harper Perennial.
5. Czerwińska-Lubszczyk, A. et al. (2022). *Zarządzanie kreatywnością i innowacyjnością w przedsiębiorstwie.* Towarzystwo Naukowe Organizacji i Kierownictwa. Dom Organizatora, TNOiK "Dom Organizatora".
6. Gajdzik, B. et al. (2022). *Czynnik ludzki w twórczej organizacji.* Towarzystwo Naukowe Organizacji i Kierownictwa „Dom Organizatora", https://managementpapers.polsl.pl/wp-content/uploads/2023/01/Czynnik-ludzki-w-twórczej-organizacji.pdf
7. Grygiel, W. (2015). *Mózg jako struktura dyssypatywna. Dusza - umysł - wolna wola*. PAN, National Information Processing Institute.
8. Knefel, M. (2018). *Smart specialization in tourism as a tool for regional development*. Doctoral dissertation, https://www.wbc.poznan.pl/publication/540635

9. Matacz, J. et al. (2022) Płyń przez życie na fali flow – jak działa zjawisko przepływu? *Tutoring Gedanensis 7(3),* 73-81. ISSN 2451-1862, doi: https://doi.org/10.26881/tutg.2022.3.08
10. Nitsch, V., Rick, V., Kluge, A., Wilkens, U. (2024). *Human-centered approaches to AI-assisted work: the future of work?* Zeitschrift für Arbeitswissenschaft.
11. Plucker, J.A., Makel, M.C. (2010). Assessment of creativity. In: R.J. Sternberg, J.C. Kaufman (Eds.), *The Cambridge handbook of creativity* (pp. 48-73). Cambridge: Cambridge University Press.
12. Porczyńska-Ciszewska, A. (2013). *Cechy osobowości a doświadczanie szczęścia i poczucie sensu życia*. Wydawnictwo Uniwersytetu Śląskiego.
13. Radoń, S. (2018). Stany świadomości w świetle neuronauk. *Annales Universitatis Mariae Curie-Skłodowska, Vol. XXXI, 1.*
14. Raport FDP (2020). *Sztuczna inteligencja w Polsce – kompetencje ekspertów AI.* ISBN: 978-83-951530-7-5. Fundacja Digital Poland.
15. Ryff, C.D., Singer, B. (2004). Paradoksy kondycji ludzkiej: dobrostan i zdrowie na drodze ku śmierci. In: J. Czapiński (ed.), *Psychologia pozytywna. Nauka o szczęściu, zdrowiu, cnotach i sile człowieka*.
16. Szmidt, K. (2017). *Edukacyjne uwarunkowania rozwoju kreatywności*. Wydawnictwo Uniwersytetu Łódzkiego.
17. Wyrzykowska, B. (2020) Teal Organizations: Literature Review and Future Research Directions. *Central European Management Journal, Vol. 27, No. 4*, pp. 124-141, ISSN: 2658-0845
18. Ziębicki, B. (2020). Holakracja jako nowa koncepcja elastycznej organizacji - próba oceny. *Przegląd Organizacji, No. 2(961)*, pp. 3-10.

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METHODOLOGICAL COMPARISON OF LANE DESIGN APPROACHES UNDER TERMINAL TRAFFIC CONDITIONS IN ŚWINOUJŚCIE

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Purpose: The aim of the study was to look at the challenges posed by the construction of a new container terminal in Świnoujście - both from a technical, operational, environmental and socio-economic perspective. The authors focused on how shipping infrastructure can be designed in a modern, safe and sustainable way. A comparison of several methods for determining the width of the fairway was made to assess which one would work best. This will enable an understanding of how to make better decisions when planning such large investments.
Design/methodology/approach: For the study, fairway width calculations were made using three methods - Canadian, PIANC and USACE - and the resulting data were collated to better understand the discrepancies. The study also made references to current research about risk in ports and the need for responsible and sustainable investment.
Findings: The results of the analysis suggest that the discrepancies between the results of the different methods highlight the importance of an informed choice of tools and design components. It was emphasised that a flexible approach to design is needed to take into account changing climatic, technical and social conditions. The importance of implementing infrastructure monitoring systems was emphasised.
Research limitations/implications: The scope of the analysis was partly limited by the availability of up-to-date technical and environmental data, which necessitated the use of simplifications that could affect the precision of the results. In the future, it would be worth extending the study to include computer simulations based on real hydrodynamic and meteorological data and comparing the results with similar investments in other ports to better adapt solutions to local conditions.
Practical implications: The results presented can be a valuable resource for practitioners - from port managers to planning and investment professionals. They highlight the importance of a holistic approach - combining technical issues with analysis of risk, environment and social considerations. This can help avoid costly design mistakes and better prepare for future operational challenges.
Social implications: The study highlights the impact of such investments on local communities and the environment. They can contribute to more open community dialogue and better policy decisions. Sustainable port planning affects not only the economy, but also the quality of life of residents and the state of the environment.

Originality/value: The publication has a practical aspect, being based on a real case study of the planned construction of a container terminal in Świnoujscie. It compares fairway design methods in relation to local conditions. It provides a tool for those involved in port infrastructure development.
Keywords: risk management, container terminal, port infrastructure, sustainability, maritime transport, sustainable maritime.
Category of the paper: Viewpoint.

1. Introduction

The importance of the development of port infrastructure in Świnoujście in the context of maritime traffic in the Baltic Sea is a key element of the strategy to strengthen the position of seaports in the area. The increase in transhipment operations and the growing demand for efficient logistics solutions require modern investments in port infrastructure. As one of the most important ports in Poland, Świnoujście plays a key role in ensuring the competitiveness of the national maritime economy and its integration into global supply chains. The planned container terminal investment - its scale and challenges represent one of the largest infrastructure investments in the region. The scope of the project includes the expansion of existing quays, the modernisation of the handling infrastructure and the implementation of advanced maritime traffic management systems. Challenges related to the implementation of the investment include technical, economic, environmental and social issues that must be taken into account in the planning and risk management process.

The safety and efficiency of container terminals depend on optimum maritime traffic management, including the proper designation of lane widths for vessels. In Świnoujście, where maritime traffic intensity is steadily increasing, it is necessary to apply appropriate methods for determining the widths of shipping lanes, taking into account both hydrotechnical parameters and operational requirements of port users. The aim of this research study is to compare methods for determining lane widths in the context of the container terminal in Świnoujście, taking into account current maritime traffic intensity. The analysis includes both theoretical models and practical solutions implemented in international ports. In order to achieve this objective, the following research hypothesis was put forward, according to which the use of computational methods based on precision navigation systems - such as approaches like USACE and PIANC - makes it possible to significantly reduce the required fairway width without compromising the level of safety, provided that the speed of vessels is properly managed.

In this paper, the research hypothesis is proven on the basis of a comparative computational analysis of three methods of determining fairway widths (PIANC, Canadian method and USACE), for two types of vessels (MSC GULSUN and BALTIMAX), and in the context of

sea traffic density in Świnoujście, a collision risk analysis for the PIANC and USACE methods was also carried out.

Various approaches to risk management in container terminals have been presented in the literature. Khorram (2020) proposed a novel risk assessment method combining formal safety assessment (FSA) with FAHP methods, entropy measure and the VIKOR model to optimise risk management at container terminals (Khorram, 2020). In contrast, a study by Orymowska et al. (2022) used the MICMAC structural analysis method for risk prioritisation at marine terminals. An empirical study at the port of Sfax in Tunisia identified key risk variables requiring immediate intervention and analysed the interdependencies between them (Orymowska, et al. 2022). Pallis (2017) presented a conceptual methodology for risk management in container terminals, based on the adaptation of formal security assessment (FSA) to the specificities of ports. This methodology takes into account a variety of risk factors and their interactions, offering a decision-making framework for assessing and improving security levels at terminals (Pallis, 2017).

These various approaches highlight the importance of comprehensive and port-specific risk management in container terminals. In this paper we will focus on the application of the PIANC guidelines, which offer proven methods and recommendations for the design and management of port infrastructure, adapted to the specific operational conditions of the container terminal in Świnoujście.

The originality of this paper lies in the comprehensive comparison of three recognised methods for determining fairway widths (PIANC, Canadian method, USACE) in the context of the planned container terminal investment in Świnoujście.

The approach allows the spatial and operational effectiveness of the individual methods to be assessed and provides a basis for making practical design recommendations to support safe and sustainable port infrastructure planning.

1.1. Modern methods for determining the width of waterways and analysis of previous studies

Modern research on the width of waterways in container terminals focuses on optimising port infrastructure, taking into account traffic intensity, navigational safety and the impact of environmental factors. In recent years, simulation and numerical methods have developed significantly, allowing for more precise modelling of fairway parameters and their adaptation to dynamically changing navigation conditions.

The Permanent International Association of Navigation Congresses provides key guidelines for fairway design, taking into account hydrodynamic and operational factors (Baric et al., 2019). Computer simulations play a key role in predicting the dynamics of ships in confined port spaces (Chen et al., 2023). The US Army Corps of Engineers indicates that an approach based on real hydrodynamic conditions and the analysis of historical vessel traffic data allows for better adaptation of fairway infrastructure to local navigation conditions (He et al., 2022).

In a similar vein, dynamic berth allocation in automated container terminals influences the design of the manoeuvring space, which is reflected in model analyses (Kastner et al., 2023).

The integration of GIS and artificial intelligence systems is one of the key directions in the development of fairway width optimisation (Liu et al., 2024). Numerical modelling indicates that the appropriate layout of container terminal yards can significantly affect their operational efficiency (PIANC, 2014). The diversity of container terminal layouts and their impact on port operations remain a significant issue in maritime logistics research (Przywarty et al., 2020), emphasising that despite efforts to standardise, local conditions continue to play a key role in the design of port infrastructure.

The analysis of fairway widths is also based on field methods and analytical models. The use of kinematic methods to determine the safe width of bends in fairways allows for more precise design of navigation routes, taking into account the trajectories of vessels in real conditions (Rodrigue, 2025). Deterministic models that take into account the effect of the shore for slim-shaped vessels provide important data for designing fairways in confined spaces (USACE, 2006).

From the perspective of port efficiency and sustainable development, the analysis of container flows allows for more accurate planning of yard capacity in container terminals, which translates into more effective management of container traffic and optimisation of terminal layout (Wang et al., 2019).

In conclusion, the literature points to the growing role of numerical modelling, artificial intelligence integration and historical data analysis in fairway width optimisation. Future research should focus on adaptive traffic management systems and dynamic modelling of hydrological conditions, which will allow for better adaptation of port infrastructure to changing environmental and operational conditions.

2. Methodology

The paper uses a comparative-computational approach, based on two recognised methodologies: PIANC and USACE. Both methods use quantitative technical parameters to determine fairway widths and to assess the safety of navigation under intensive maritime traffic conditions. The analysis aimed to identify the differences resulting from the application of different design and technological assumptions and their impact on the efficiency and safety of the planned investment in Świnoujście. The methodology adopted includes both engineering calculations related to the dimensioning of the fairway and risk analysis in port operations.

As a first step, calculations of the fairway width were carried out using the Canadian method, which is based on empirical relationships and actual operating conditions. In order to compare the results, the fairway was also dimensioned using the PIANC (Permanent

International Association of Navigation Congresses) method, which is recognised as the standard for international navigation infrastructure design. In addition, values obtained using the USACE (United States Army Corps of Engineers) method, which takes into account the influence of modern navigation systems on the width of the required waterway, were analysed.

In the next stage of the study, a risk analysis was applied, involving the identification of potential risks associated with the operation of the fairway and the container terminal. A multi-criteria analysis was used for this purpose, taking into account technical, operational and environmental aspects. A Monte Carlo method was also used as part of the analysis, allowing a probabilistic estimation of the risk of collision on the fairway.

The study was based on literature data, analyses of historical maritime incidents and simulations of navigational conditions. The results of the calculations and analyses made it possible to assess the effectiveness of various fairway dimensioning methods and to identify optimal solutions to increase the safety and operational efficiency of the port infrastructure.

2.1. Characteristics of the area and traffic intensity

The port in Świnoujście is a key transport hub in the Baltic Sea area, playing a strategic role in Poland's maritime economy. Its infrastructure includes advanced transhipment terminals, and planned investments include the construction of a modern container terminal, which will significantly increase the port's capacity to handle large tonnage vessels. In addition, extensive navigation systems ensure a high level of navigational safety and efficient operation of the entire port complex (Ministry of Infrastructure, 2023).

The importance of the fairway leading to the port of Świnoujście is an indispensable element in ensuring the efficient handling of shipping and is a strategic component of the transport infrastructure. Its appropriate navigational parameters, such as depth, width and marking system, determine the port's ability to handle vessels with greater draught, including ocean-going vessels and smaller transport vessels. The importance of the fairway stems not only from its logistical function, but also from its impact on the handling efficiency and competitiveness of the port as a transport hub. According to the literature, the upgrading of the waterway is an important factor in increasing the capacity of ports and their ability to handle larger vessels. Studies indicate that the expansion of hydrotechnical infrastructure in ports increases their attractiveness for international shipping operators. In the context of Świnoujście, dredging and maintaining the waterway at appropriate technical parameters allows the port to be effectively integrated into global supply chains, as confirmed by analyses of maritime traffic and transshipment dynamics. The literature also emphasises the importance of the fairway in terms of navigational safety and protection of the marine environment (Gucma, Ślączka, 2017). Maintaining the fairway in an appropriate technical condition minimises the risk of collisions, facilitates the manoeuvring of vessels and ensures compliance with international maritime transport regulations. The fairway leading to the port of Świnoujście plays a fundamental role in the functioning of the maritime transport system. Its development and modernisation are

a prerequisite for increasing the competitiveness of the port and its effective integration into global shipping routes. This enables ocean-going vessels and smaller transport ships to enter the port. It is a key piece of infrastructure as it provides with efficient access to the transhipment terminals, which directly affects the efficiency and competitiveness of the port.

2.2. Modernisation of the fairway

Modernisation of the Świnoujście-Szczecin fairway includes deepening and widening the track, reinforcing the bottom and slopes to prevent erosion, installing modern navigation systems and signage, as well as building and modernising breakwaters and quays. These measures significantly improve the capacity of the fairway and navigational safety, which translates into an increase in the port's handling potential. As part of this project, the waterway, with an original depth of 12.5 metres, was deepened to 14.5 metres, allowing vessels of up to 50,000 DWT (Deadweight Tonnage) to call at the port. The deepening of the fairway made it possible to adapt the port to handle Panamax-class ships, which significantly increased its competitiveness compared to other Baltic ports. The increased depth and width of the fairway has allowed the port to be better integrated into global supply chains, making it an attractive destination for international shipowners and logistics operators.

2.3. Hydrometeorological conditions

The Świnoujście area is characterised by variable hydrometeorological conditions that affect port operations and shipping safety. Strong north-westerly winds and dynamic changes in atmospheric pressure can cause manoeuvring difficulties, particularly during stormy periods. According to data available on WeatherOnline, the average wind speed in the Świnoujście area is between 2 and 4 on the Beaufort scale. During storm periods, wind speeds can increase significantly. For example, in December 2024, the Institute of Meteorology and Water Management (IMGW) issued a warning of winds reaching an average speed of up to 85 km/h (about 23.6 m/s), with gusts as high as 115 km/h (about 31.9 m/s). Such conditions may cause manoeuvring difficulties in the area of the planned development, especially during storms.

Sea currents are also an important factor affecting navigational safety, with average speeds in the fairway area ranging from 0.5 to 1.2 m/s (Gucma et al., 2021). The variability of these conditions requires the use of precise navigation aids, including Vessel Traffic Service (VTS) systems. Limited visibility is one of the main operational challenges in the Świnoujście area, especially during the autumn and winter months. Fog phenomena can reduce visibility to below 200 metres, requiring the use of advanced nautical support systems. In and around the port, there is an extensive radar system as well as an Automatic Identification System (AIS), which makes it possible to precisely track the position of ships. In addition, the use of state-of-the-art hydrometeorological monitoring systems allows for real-time forecasting of atmospheric conditions, which significantly increases the safety of port operations. A remote control system

for vessel traffic in the approach area was also implemented in 2022, allowing for more efficient traffic management in conditions of limited visibility.

Overview of methods for determining lane widths

The design of lane widths in navigable water bodies requires the use of various methods that take into account both international standards and the specifics of local navigational conditions. Three main approaches are distinguished in the literature: analytical, simulation and empirical methods.

The analytical methods are based on standardised standards developed by international organisations such as PIANC (Permanent International Association of Navigation Congresses) and IALA (International Association of Marine Aids to Navigation and Lighthouse Authorities). These guidelines set minimum values for lane widths depending on vessel size, hydrometeorological conditions and the degree of manoeuvring space limitation. Gucma et al. (2022) presented a generalised analytical method based on the analysis of hydrodynamic conditions and vessel trajectories, taking into account the width of the safe basin for bulk carriers at fairway bends. These studies showed that classical analytical models often need to be adapted to real navigational conditions, especially for bodies of water with limited manoeuvring space (Gucma et al., 2022).

With the development of computer technology, navigation simulators are increasingly being used to determine optimal lane width parameters. Simulation methods allow real navigation scenarios to be modelled and the influence of various factors such as wind, currents or the movement of other vessels to be analysed. A study by Artyszuk et al. (2016) shows that the use of simulation models in the fairway design process allows lane widths to be adapted to actual operating conditions (Artyszuk et al., 2016). The simulation results allow precise definition of safety zones, minimising the risk of collisions and improving the capacity of the shipping infrastructure. Taking into account the specific characteristics of large container ships (e.g. ULCS - Ultra Large Container Ships) In the context of the increasing size of vessels such as Ultra Large Container Ships (ULCS), it is necessary to adapt lane widths to the specific manoeuvring requirements of these vessels. Gucma & Przywarty (2020) conducted simulation tests on fairways, analysing the minimum lane widths required for the safe navigation of large vessels. The results showed that the lane widths need to take into account a larger passing distance and adapt the fairway parameters to the specific hydrodynamic characteristics of the ULCS (Gucma, Przywarty, 2020).

Empirical methods are based on the analysis of historical data from actual navigation operations. This approach allows conclusions to be drawn based on the actual behaviour of ships under specific conditions. Montewka & Przywarty (2005) used historical data from port operations to determine the actual distribution of ship trajectories and to determine the optimal lane widths (Montewka, Przywarty, 2005). The results of the study showed that taking into account the actual traffic trajectories allows the width of the fairways to be adapted to the actual operating conditions and not only to normative guidelines.

Each of the methods used in the process of determining lane widths has its advantages and limitations. Analytical methods provide a standardised approach, but may require adaptation to local conditions. Simulation methods enable accurate modelling of different traffic scenarios, while empirical methods are based on real data, which increases their reliability. Optimal solutions often combine these approaches to achieve the best results in water traffic planning and management.

When designing the new container terminal in Świnoujście and the deepening of the waterway, it is crucial to take into account the parameters of the largest vessels that the new quays will be able to handle. In this case two classes of vessels have been adopted as reference (Table 1):

- MSC Gulsun (Megamax-24 class) - the largest container ship to call at the port of Gdansk.
- Baltimax - a class of vessel optimised for Baltic navigation.

Table 1.
Summary of operational and technical parameters of selected vessels

Parameter	MSC Gulsun (Megamax24)	Baltimax
Overall length (LOA)	399,9 m	330 m
Width (BOA)	61,5 m	48-50 m
Maximum draught	16,5 m	15 m
Capacity (TEU)	23,756 TEU	12 000-15 000 TEU
Operating speed	22.5 knots	20-22 knots
Drive	MAN Diesel & Turbo engine	MAN B&W engine

Source: Own compilation based on data from MarineTraffic.

The modernisation of the approach track in Świnoujście is a key element in adapting the port to handle the largest container ships. The MSC Gulsun, representing the Megamax-24 class, has a draught of 16.5 m, a width of 61.5m and a length of 400m, which requires a fairway depth of at least 19.5 m and a width of 200-250 m. For Baltimax class vessels, with a maximum draught of 15.0 m, the existing fairway (depth 14.5 m, width 180-200 m) is insufficient. Increasing the bend radius of the track to 3,000m will ensure safe manoeuvring, eliminating the risk of collisions and optimising the approach time to the port. The new approach track parameters will allow for an increase in container handling and attract global operators. Table 2 shows a comparison of the approach track parameters in Świnoujście - before and after modernisation.

Table 2.
Parameters of the approach fairway in Świnoujście - before and after modernisation

Parameter	Before modernisation	After modernisation
Track depth	14,5 m	19,5 m
Track width	180-200 m	200-250 m
Corner radius	~2 000 m	3000 m
Track length	32 nautical miles	No change
Supported vessels	Up to 13,500 TEU	Up to 24,000 TEU
Max. draught	13,5 m	16,5 m
Max. vessel width	48 m (Baltimax)	61.5 m (Megamax-24)

Source: Own compilation based on data from Szczecin-Świnoujście Port Authority.

The current infrastructure allows the handling of large vessels, but not the largest container vessels of the Megamax-24 class. The approach track after the upgrade will be adapted to the largest container vessels.

Figure 1 shows a diagram of the planned container terminal (shown in red and yellow).

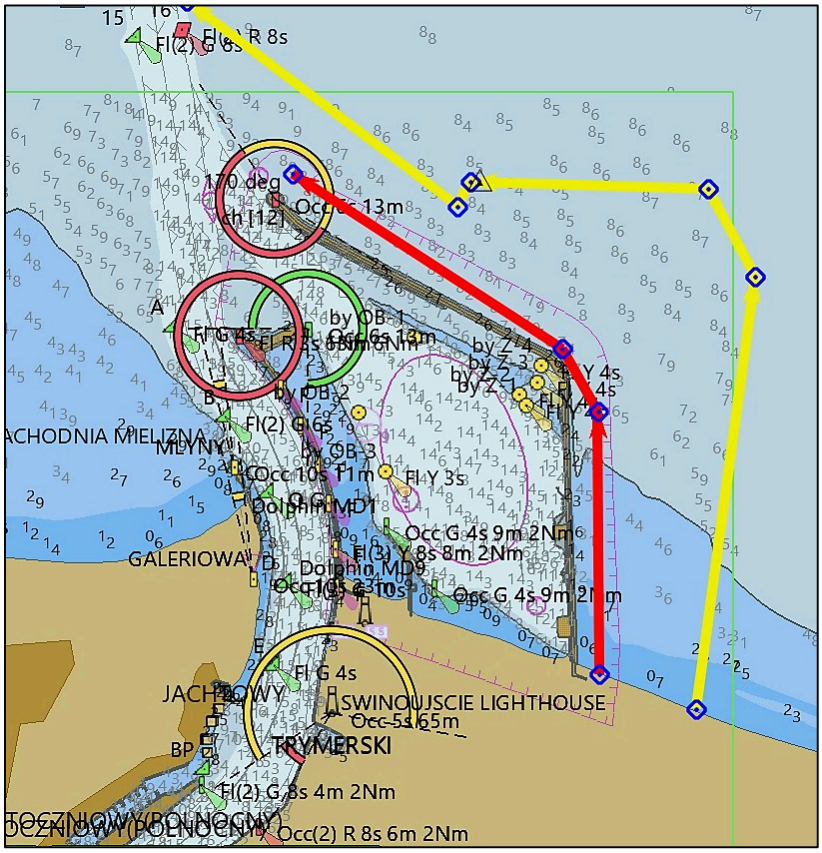

Figure 1. Diagram of the planned container terminal.

Source: The study was independently prepared using the tools available in OpenCNP.

2.4. Criteria for assessing fairway dimensioning methods

Criteria for evaluating methods to design fairways focus on navigational safety, operational efficiency and flexibility in traffic management, which is important for ports with high maritime traffic (PIANC, 2014; USACE, 2018). Shipping safety ensures that the risk of collision is minimised through appropriate track widths, taking into account parameters such as ship manoeuvrability and hydrometeorological conditions (PIANC, 2014). Infrastructure capacity refers to the capacity of the terminal and fairway, which affects the number of vessels to be handled, as well as the timing of port manoeuvres (USACE, 2018). The ability to regulate the movement of vessels relates primarily to the ability to adapt the navigation infrastructure to increasing vessel sizes and changes in global maritime transport (PIANC, 2020). The PIANC and USACE methods differ in their approach - PIANC focuses on navigational standards, while USACE considers dynamic traffic modelling and the influence of environmental factors (USACE, 2018). Dimensioning tracks according to these criteria enables optimisation of port infrastructure and increased operational efficiency.

Figure 2 shows the key navigational parameters, including the course change of vessels, relevant to determining the required lane width at the bend in the waterway, which has a direct impact on the safety and smoothness of navigation in the area of the container terminal in Świnoujście.

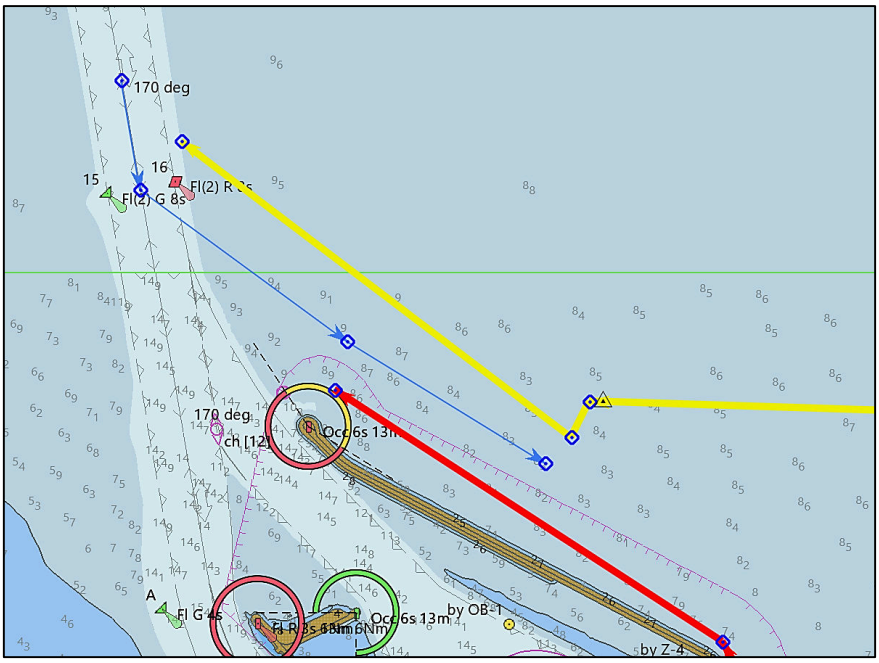

Figure 2. Navigational parameters relevant for determining the required lane width at the waterway bend.

Source: The study was independently prepared using the tools available in OpenCNP.

2.5. Dimensioning of the two-way fairway using the PIANC method

PIANC (Permanent International Association of Navigation Congresses) is an international organisation dealing with standards for the design of water infrastructure, including fairways, locks and ports. The dimensioning of fairways according to PIANC recommendations takes into account factors such as vessel width, hydrometeorological conditions, manoeuvrability of vessels and safety rules. The PIANC method is based on the determination of the minimum width of the fairway based on the width of the vessels (the largest vessel operating in the fairway), the safety margins - determined by the influence of currents, waves and navigational conditions and additional requirements - resulting from the characteristics of the port and vessel traffic. In the case of a bi-directional fairway, a key aspect of dimensioning is to ensure the safe passing of vessels in counter-rotating traffic, which requires consideration of the minimum track width.

Table 3 and Table 4 show the components that were used for the PIANC calculations. For the selected vessels these include parameters such as the fairway width and the depth required for safe navigation. For a container ship, the parameters analysed are the manoeuvring width depending on the hydrodynamic conditions and the minimum depth adapted to its draught and wave motion, while for an oil tanker, larger bend radii and additional safety reserves in the track depth due to its weight and limited manoeuvrability were taken into account.

Table 3.
Components used in the calculation for MSC GULSUN

PIANC components	Type of amendment	Symbol	Amendment value
Additional amendment			
Vessel speed	V > 12 w	di1	0,1 B
Prevailing wind	15-33 w	di2	0,3 B
Cross current	0,2-0,5 w	di3	0,2 B
Longitudinal current	V < 1.5 w	di4	0,0 B
Height and wave length	3 m >hf > 1 m	di5	2,0 B
Navigational markings	good	di6	0,1 B
Bottom type	soft bottom	di7	0,0 B
Depth to draft	h/T > 1.5	di8	0,2 B
Type of cargo	all others	di9	0,0 B
Reserve left (open track)	V > 12 in	drc	0,7 B
Reserve right (open track)	V > 12 in	drz	0,7 B
Width of manoeuvre		dm	
Manoeuverability of the vessel	very good handling	dm	1,3 B
Two-way traffic			
Delimitation lane components (vessel speed)	V = 8-12 in	dpj1	1,6 B
Delimitation lane components (traffic intensity)	Large (> 3.0 vessels/h)	dpj2	0,5 B
Components used to calculate the lane on the bend			
Return angle [^{0}]		ΔΨ	
Vessel speed [m/s]		V	
One-way traffic factor		F	
Curve radius at the bend [m]		Ro	
Minimum required visibility from the bridge of the vessel [m]		s	
Vessel steering ratio		kz	

Table 4.
Components used in the calculation for the BALTIMAX vessel

PIANC components	Type of amendment	Symbol	Amendment value
Additional amendment			
Vessel speed	V > 12 w	di1	0,1 B
Prevailing wind	15-33 w	di2	0,3 B
Cross current	0,2-0,5 w	di3	0,2 B
Longitudinal current	V < 1.5 w	di4	0,0 B
Height and wavelength	3 m >hf > 1 m	di5	1,0 B
Navigational markings	good	di6	0,1 B
Bottom type	soft bottom	di7	0,0 B
Depth to draft	1,25-1,5	di8	0,1 B
Type of cargo	all others	di9	0,0 B
Reserve left (open track)	V > 12 in	drc	0,7 B
Reserve right (open track)	V > 12 in	drz	0,7 B
Width of manoeuvre			
Manoeuverability of the vessel	very good handling	dm	1,3 B
Two-way traffic			
Delimitation lane components (vessel speed)	V = 8-12 in	dpj1	1,6 B
Delimitation lane components (traffic intensity)	Large (> 3.0 vessels/h)	dpj2	0,5 B
Components used to calculate the lane on the bend			
Return angle [^{0}]		ΔΨ	
Vessel speed [m/s]		V	
One-way traffic factor		F	
Radius of curve on bend [m]		Ro	
Minimum required visibility from the bridge of the vessel [m]		s	
Vessel steering ratio		kz	

2.6. Dimensioning of the fairway using the Canadian method

Designing fairways requires a precise approach based on proven engineering methods that take into account both the safety and efficiency of navigation. One popular technique used in fairway dimensioning is the Canadian method, based on empirical relationships derived from real-world studies. In practice, it is often combined with the PIANC guidelines to form a hybrid approach to determining key fairway parameters. The method takes into account important factors such as the width of the track, its depth, curve radii and navigational conditions, ensuring optimal conditions for vessel traffic. Its application allows the parameters of the water infrastructure to be determined in a way that is adapted to the specific hydrodynamic conditions and operational requirements. In practice, algorithms based on this method integrate empirical relationships from the PIANC and Canadian methods, enabling efficient design of fairways under different navigational conditions (Zalewski, 2012). The components used in the calculations can be found in Table 5.

Table 5.
Components used in the Canadian Method

Components of the Canadian Method	**Type of amendment**	**Symbol**	**Amendment value**
Additional amendment			
Prevailing wind	15-33 w	dd3	0,3 B
Cross current	0,2-0,5 w	dd4	0,2 B
Controllability of the vessel	0,75-1,25 B	dd5	1,0 B
Navigational markings	good	dd6	0,1 B
Bottom type	soft bottom	da3	0,0 B
Type of cargo	all others	da1	0,0 B
Depth/depth ratio	1.15 < h/T < 1.5	da2	0,2 B
Correction for visibility and time of day		da4	0,0 B
Correction for high ship speeds		da5	0,1 B
Width of manoeuvre		dd1	
Controllability of the vessel	very good handling	dd1	1,3 B
Two-way traffic			
Delimitation lane components (traffic intensity)	Large (>3.0 vessels/h)	dd2	0,5 B
Components used to calculate the lane on the bend			
Return angle [^{0}]		$\Delta\Psi$	
Vessel speed [m/s]		V	
One-way traffic factor		F	
Radius of curve on bend [m]		Ro	
Minimum required visibility from the bridge of the vessel [m]		s	
Ship steering ratio		kz	

3. Results

The United States Army Corps of Engineers (USACE) method takes a comprehensive approach to fairway design, based on an analysis of dynamic navigation conditions, taking into account the width of vessels, hydrodynamic effects, safety margins and the influence of hydrometeorological conditions (Emery, 2024).

The American method for determining track gauge, is particularly useful in the analysis of fairways with variable navigational conditions, where it is necessary to model ship traffic based on empirical data and hydrodynamic simulations. It makes it possible to adapt the track width to extreme conditions, such as strong currents, large tidal amplitude or wave influence (Emery, 2024). In this way, the USACE method ensures a high level of safety and efficient management of maritime traffic, which is crucial for ports with heavy traffic.

In order to correctly calculate and dimension the fairway for the Świnoujście terminal, the following data must be collected:

- Parameters of the largest vessels served (MSC Gulsun - Megamax24 class);
- Hydrographic parameters of the fairway- atmospheric and hydrological conditions;
- Traffic volume and operational analysis- shipping intensity data;

The components used in the United States Army Corps of Engineers (USACE) calculations include key hydrodynamic, navigational and operational parameters that determine the dimensioning of the fairway. The following table shows the key factors considered in the analysis (Table 6).

Table 6.
Components used in the USACE calculations

Fixed waterway cross-section, very good navigational aids - one-way traffic	
Cross-section of the waterway:	Dredged fairway
Current speed:	0,5-1,5 w
Component value:	3,25 B
Fixed waterway cross-section, very good navigational aids - two-way traffic	
Cross-section of the waterway:	Dredged fairway
Current speed:	0,5-1,5 w
Component value:	5,5 B

The design of fairways requires the consideration of many factors, such as the size of vessels, their manoeuvrability, hydrographic conditions or the availability of navigation systems. Each calculation method makes different assumptions about the safety and efficiency of navigation, which affects the resulting values for fairway widths. Table 7 shows the calculation of waterway widths based on the selected methods in the study.

Table 7.
Calculation of waterway widths based on selected calculation methods

MSC GULSUN	BALTIMAX
Straight section of waterway calculated using the PIANC method	
One-way	
282,90 m	225,00 m
Two-way	
695,95 m	555,00 m
Section at the bend of the waterway calculated using the PIANC method and the Canadian method	
One-way	
288,98 m	241,72 m
Two-way	
707,11 m	571,72 m
Canadian method on a straight stretch of road	
Two-way	
227.55 m	185,00 m
A rectilinear section of the waterway calculated using the USACE method - a fixed section of the waterway with very good navigational aids	
One-way	
199,87 m	162,50 m
Two-way	
338,25 m	275,00 m

The analysis of the results obtained based on the comparison of the methods on the straight section predicts the greatest widths with the PIANC method. For one-way traffic, it is 282.90 m for MSC GULSUN and 225.00 m for BALTIMAX, a difference of 57.90 m. For two-way traffic, these values increase to 695.95 m and 555.00 m respectively, giving an even greater difference of 140.95 m. The Canadian method, which is used for straight sections of track, shows a smaller width requirement than PIANC. For MSC GULSUN, the width obtained is 227.55 m, while for BALTIMAX it is 185.00 m, a difference of 42.55 m in favour of the smaller vessel. It is worth noting that, compared to the PIANC method, these differences are significant - the waterway width is 55.35 m less for MSC GULSUN and 40.00 m less for BALTIMAX. The most compact waterway width values result from calculations using the USACE method, which assumes the use of modern navigation systems that allow safe manoeuvring in a narrower body of water. For MSC GULSUN, 199.87 m (one-way) and 338.25 m (two-way) were obtained, and for BALTIMAX 162.50 m and 275.00 m respectively. This means that, compared to PIANC, the USACE method allows a track width reduction of 83.03 m (MSC GULSUN) and 62.50 m (BALTIMAX) for one-way traffic and 357.70 m and 280.00 m for two-way traffic. In contrast, additional manoeuvring space is required at the bends. The fairway width values increase compared to the straight sections. For one-way traffic, MSC GULSUN requires 288.98 m and BALTIMAX 241.72 m, a difference of 47.26 m. For two-way traffic, the values are 707.11 m and 571.72 m respectively, where the difference increases to 135.39 m.

Figure 3 shows a comparison of the fairway limits determined by the PIANC method for the MSC GULSUN in one-way traffic with the currently existing fairway. This comparison helps to illustrate the differences in required track width and the potential upgrade needs resulting from the operation of larger vessels. Figure 4 shows the one-way and two-way track (red) calculated using the PIANC method. The width of the two-way track is much wider, almost 2.5 times wider than the one-way track.

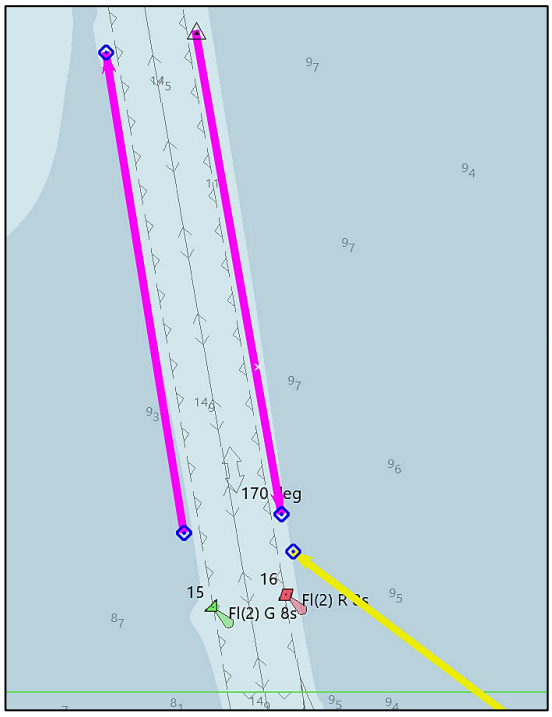

Figure 3. Boundaries of the fairway calculated using the PIANC method for the MSC GULSUN ship, unidirectional, compared to the existing fairway.

Source: The study was independently prepared using the tools available in OpenCNP.

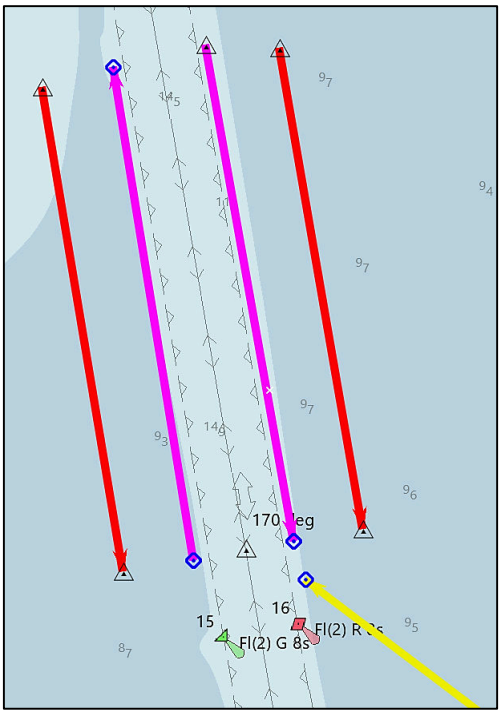

Figure 4. One-way and two-way track calculated using the PIANC method.

Source: The study was independently prepared using the tools available in OpenCNP.

Figure 5 illustrates the widening of the fairway at the curve of the road, taking into account the optimisation of the track width for Baltimax vessels. An analysis based on the PIANC method allows the required navigational space to be determined precisely, minimising the risk of collision and ensuring safe navigation conditions.

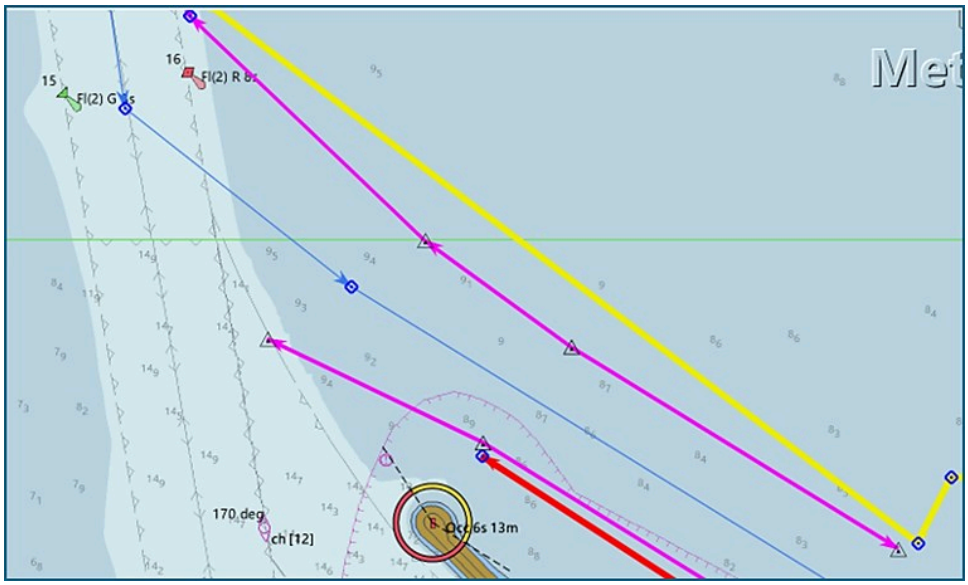

Figure 5. Widening of the fairway at the curve of the road, taking into account the optimisation of the track width for Baltimax vessels.

Source: The study was independently prepared using the tools available in OpenCNP.

Figure 6 shows the designated section of the fairway for the Baltimax vessel, taking into account the width constraints due to the limited area of the planned port infrastructure. This analysis assesses the impact of the infrastructure on the availability and manoeuvrability of the vessels in the port basin, indicating potential upgrade needs.

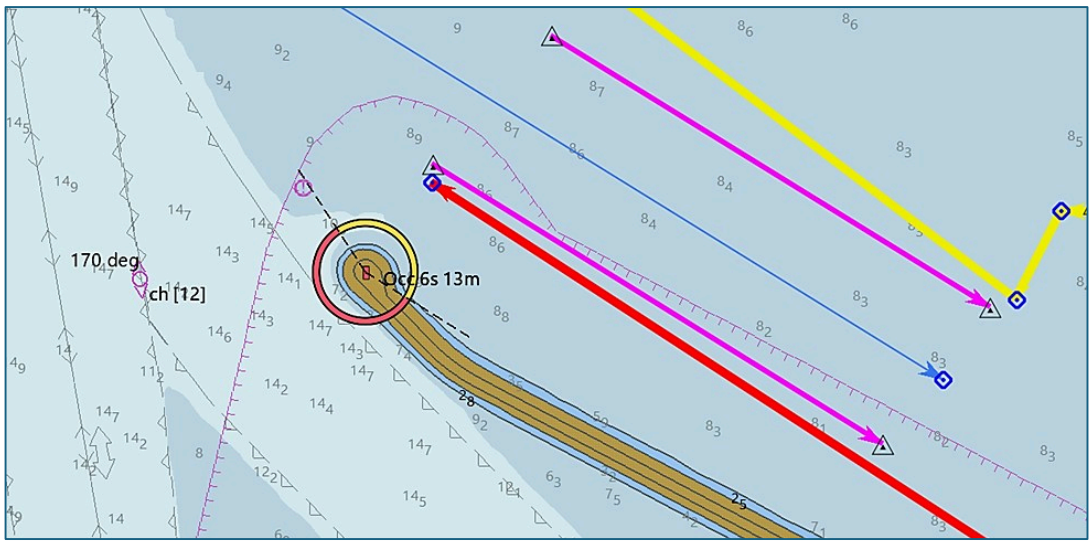

Figure 6. Designated fairway section for the Baltimax vessel.

Source: The study was independently prepared using the tools available in OpenCNP.

Figure 7 shows a comparison of the fairway widths calculated by the different methods, allowing an assessment of their impact on the safety and efficiency of navigation. This analysis takes into account the variants of fairway dimensioning, indicating the differences due to the calculation assumptions made and the specificities of each method.

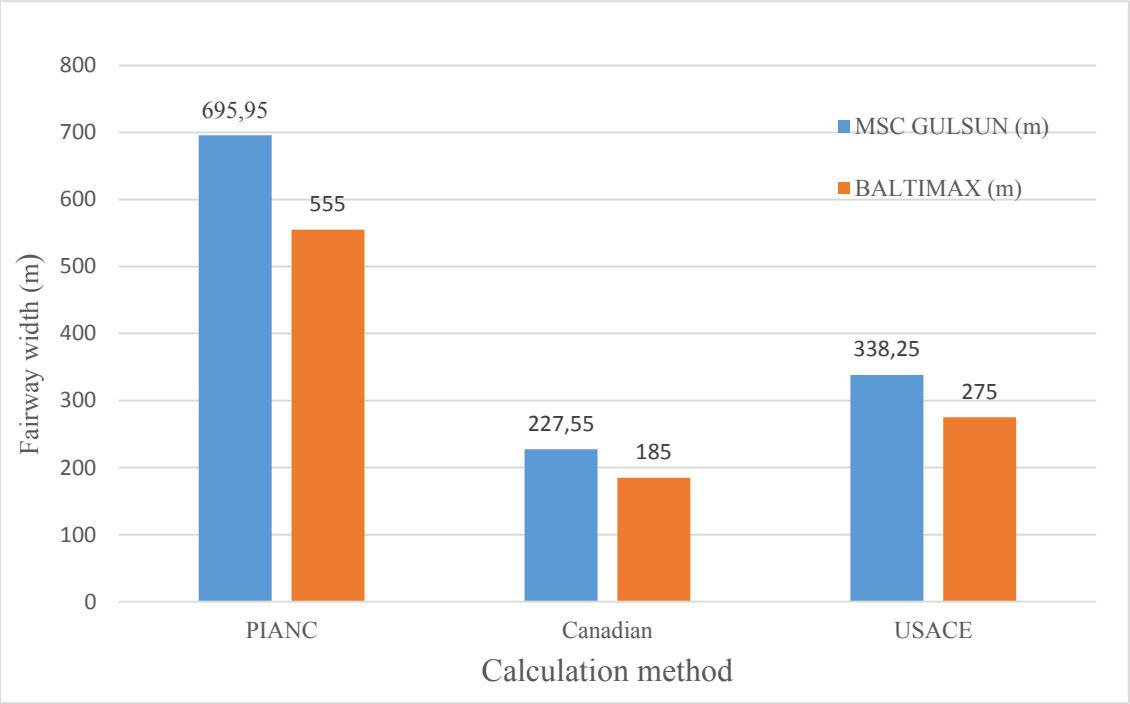

Figure 7. Comparison of fairway widths by PIANC, USACE and Canadian methods.

Comparing the fairway widths for the different calculation methods (PIANC, Canadian, USACE) for the two selected vessels, it can be seen that the PIANC method requires the largest fairway widths, especially for the MSC GULSUN, while the USACE method allows for significant width reductions due to advanced navigation systems. The PIANC method also requires larger fairway widths for two-way traffic as well. The Canadian method reduces the width of the fairways by about 15-20% compared to PIANC. In contrast, the USACE method, through the use of precision navigation systems, reduces track widths by up to 40-50% compared to PIANC. The bends require wider tracks than the straight sections, with differences between the two averaging 5-10%.

In order to analyse the impact of the new approach fairway on the capacity of Świnoujście port, the following parameters were compared:

- Changing the vessels served - how the new track parameters affect vessel types.
- Increasing the number of ship calls - how the increased depth and width of the track will affect ship traffic.
- Change in the timing of manoeuvres and port operations - impact of larger vessels on operational efficiency.
- Economic implications for the port - potential increase in trade and revenue for the port.

Data based on official port reports, engineering standards (PIANC, USACE), and a comparative analysis of similar upgrades in other ports were used to calculate the impact of the Świnoujście approach fairway upgrade on port throughput. Table 8 shows a comparison before and after the approach fairway upgrade taking into account the nominal requirements of the PIANC and USACE methodologies.

Table 8.
Comparison of the Approach Fairway Before and After the Upgrade Considering the Nominal Requirements of the PIANC and USACE Methodologies

Parameter	Before modernisation	After modernisation	Growth
Supported vessels	Up to 13,500 TEU	Up to 24,000 TEU	+80%
Fairway length	32 nautical miles	32 nautical miles	-
Track width	180-200 m	200-250 m	+25%
Track depth	14,5 m	19,5 m	+35%
Number of arrivals per year	~1000	~1400-1500	+40%
Transshipments per year	~1.2 million TEU	~2.5 million TEU	+100%

Source: own compilation based on data from MarineTraffic, VesselFinder, Maritime Authority hydrographic reports, AIS data, Szczecin-Świnoujście Port Authority reports & Forecasts of the Szczecin-Świnoujście Port Authority.

The expansion of the deep-water track in Świnoujście will have a significant impact on port capacity, shipping safety and operational efficiency. The widening and deepening of the track will enable the handling of larger vessels, such as Megamax-24 class container ships, which will optimise logistics and reduce sea transport costs. In addition, it will increase the width of the track, which will improve the passing of vessels and the manoeuvrability of ships. The result is a reduction in the risk of collisions in heavy traffic. The calculated increase in approach track parameters has been calculated based on a percentage increase formula:

$$Growth = \frac{New\ Value - Old\ Value}{Old\ Value} \times 100\% \quad (1)$$

Source: (Mankiw, 2020).

This formula is commonly used in hydraulic engineering analyses, as well as in port reports to assess changes in water infrastructure. Applying the above formula to the analysis of track parameters helps to accurately determine the scale of change, which is important for strategic planning of the port and predicting its future role in the global supply chain.

Designing a fairway requires a precise determination of its width, taking into account the parameters of the vessels and the navigational conditions. This study compares three methods used in fairway dimensioning: PIANC, USACE and Canadian, focusing on two presentable container vessels - MSC GULSUN and BALTIMAX. The aim of the study was to determine the impact of selected computational methods on navigational safety and to assess the risk of collision before and after vessel speed reduction. Monte Carlo simulations were used to provide a probabilistic estimate of collision risk, taking into account variable operational parameters such as fairway width and vessel speed. The values of the input variables were selected on the basis of available literature, shipping reports and analyses of the Świnoujście-Szczecin fairway. The following assumptions were made, which are listed in Table 9.

Table 9.
Values of output variables

Vessel traffic volume	**an average of 30 units per day**
Speed of vessels	random variable with normal distribution N(10, 2) [nodes]
Speed of vessels	random variable with normal distribution N(7,1.5) [nodes]
Crew response time	random variable between **30-90 seconds**
Fairway width	values obtained by the methods
Hydrological conditions	sea currents from **0.5 to 1.2 knots**
Visibility conditions	in 30% of cases, reduced visibility of less than 2 km

The scope of the study is to compare the fairway width for MSC GULSUN and BALTIMAX depending on the sizing method used (PIANC, USACE, Canadian). For the Collision Probability Calculations for each method, both the standard speed N (10.2) [knots] and after speed reduction to N (7.1.5) [knots] were used. The analysis considered the effect of speed reduction on collision risk reduction for each method. The calculation results, visualisations and a detailed comparison of the fairway sizing methods are presented below.

Table 10 summarises the collision probabilities for the PIANC, USACE and Canadian methods before and after speed reduction. The calculations were performed in Python, based on a Monte Carlo simulation (100,000 iterations).

Table 10.
Comparison of collision probability before and after speed reduction

Method	Vessel	Collision probabilities for N (10,2) [nodes]	Collision probabilities for N (7.1.5) [nodes]
PIANC	MSC GULSUN	0,03	0,0
PIANC	BALTIMAX	1.859	0,001
USACE	MSC GULSUN	37.501	7.498
USACE	BALTIMAX	57.161	23.098
Canadian	MSC GULSUN	72.867	41,079
Canadian	BALTIMAX	86.500	55.897

Figure 8 shows a comparison of collision probabilities for MSC GULSUN and BALTIMAX vessels according to PIANC, USACE and Canadian methods, both before and after speed reduction, demonstrating the impact of speed reduction on navigational safety.

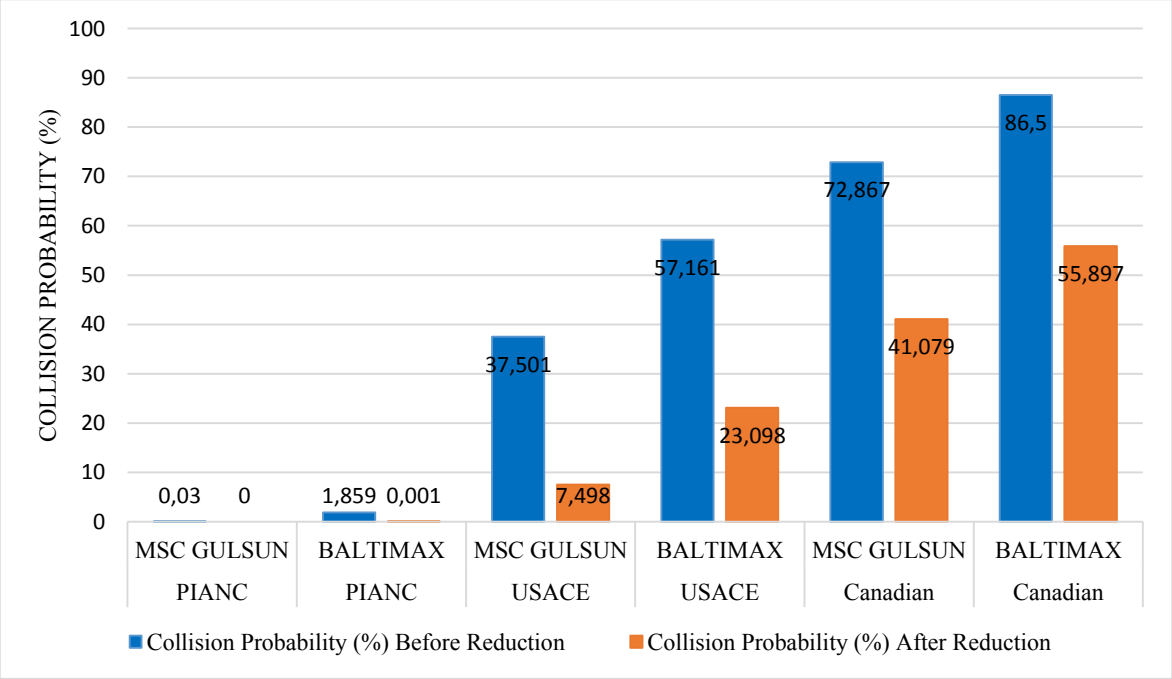

Figure 8. Comparison of Collision Probability Before and After Speed Reduction.

Based on the calculations, the PIANC method almost completely eliminates the risk of collision, especially after speed reduction - the probability is 0.000% for MSC GULSUN and 0.001% for BALTIMAX, suggesting that the predicted fairway widths are fully safe for these vessels. The USACE method shows a significant improvement after speed reduction, but the risk of collision remains at 7.5% for MSC GULSUN and 23.1% for BALTIMAX, indicating that the track widths may not be sufficient for larger vessels. The Canadian method, despite the speed reduction, still shows the highest collision risk of 41.1% for MSC GULSUN and 55.9% for BALTIMAX, suggesting that the fairway width calculated by this method is not suitable for the safe navigation of large vessels and requires additional safety measures.

4. Discussion

Based on the results of the study, a comparison of different methods for determining lane widths was carried out, taking into account both International Maritime Organisation (IMO) standard procedures and approaches used in other major container ports. The analysis showed that dynamic models, taking into account actual hydrodynamic conditions and traffic volumes, allow optimising safety and operational efficiency. The results of the study indicate that an increase in maritime traffic intensity requires a flexible approach to lane delimitation. Optimisation of shipping lane widths should take into account not only static mathematical models, but also dynamic traffic monitoring and predictive analysis based on historical and current data. The discussion of the research results points to the need to integrate modern maritime traffic monitoring technologies with navigational safety management procedures.

In the literature, studies on the planned location and functional layout of the container terminal in Świnoujście are available, such as Gucma et al. (2016). In them, the authors presented a detailed analysis of the terminal's location options, the safety zones related to the vicinity of the LNG terminal and the fairway widths determined by the CIRM method, which is based on simulation.

The implementation of traffic management systems based on artificial intelligence and predictive models will increase safety and optimise port operations.

It is worth noting that although the analysis presented here focuses on modelling and analysis of maritime traffic data, it is important to emphasise the need to include actual maritime incidents in further research details. In order to better illustrate the practical application of collision risk assessment and the implementation of flexible maritime traffic management strategies in the area of the planned container terminal.

It is recommended to implement integrated platforms such as IWRAP IALA, which allow continuous risk assessment based on actual conditions and predicted traffic scenarios. Systems of this type enable on-the-fly adaptation of operational parameters, such as fairway width, to changing maritime traffic conditions.

In addition, the contribution of artificial intelligence can support real-time vessel traffic analysis (using, for example, AIS data). It will allow the identification of potential collision risks and the optimisation of vessel entry and departure schedules from the port. This type of approach makes it possible to increase the flexibility and availability of ports in the face of dynamic developments in the structure and volume of maritime traffic.

5. Conclusions

An analysis of the modernisation of the fairway and the application of different calculation methods showed significant differences in the approach to the design of the shipping infrastructure. The modernisation carried out will significantly increase the operational capacity of the fairway. The handling of vessels will increase from a capacity of 13,500 TEU to 24,000 TEU, an increase of 80%. At the same time, the width of the track will increase by 25%, reaching a range of 200-250m, and its depth will increase from 14.5m to 19.5m, an increase of 35%. These changes will increase the number of calls per year by 40%, while the port's annual throughput will double, reaching 2.5 million TEU.

A comparison of the results obtained with the PIANC, Canadian and USACE methods showed significant differences in fairway widths. The PIANC method assumes the largest track width values, especially for two-way traffic, with a width of 695.95 m for MSC GULSUN and 555.00 m for BALTIMAX. This approach provides large safety margins to allow large vessels to manoeuvre freely. In contrast to PIANC, the Canadian method provides for smaller track widths, which is the result of a more practical approach that takes into account actual operating conditions. For the MSC GULSUN, the track width calculated by this method is 227.55 m and for the BALTIMAX 185.00 m. An even greater reduction in track width is made possible by the USACE method, which, with the use of advanced navigation systems, allows a significant optimisation of the navigable space. In this case, the track width for MSC GULSUN is 199.87 m for one-way traffic and 338.25 m for two-way traffic, while for BALTIMAX it is 162.50 m and 275.00 m respectively.

The results indicate that increasing the width of the fairway has a positive impact on safety and navigational capacity, allowing larger vessels to be handled and facilitating manoeuvring in difficult hydrographic conditions. However, the use of computational methods based on precision navigation systems, as in the case of the USACE, makes it possible to significantly reduce the width of the fairway without adversely affecting safety. The modernisation of

fairways and the optimisation of dimensioning methods are key to improving the efficiency of maritime transport and increasing the competitiveness of ports. The choice of the appropriate method should take into account the specifics of the water body, the size of the vessels to be served and the availability of modern navigation systems.

It is also important to highlight the results of the risk analysis carried out, which showed that the PIANC method provides the highest level of safety, reducing the probability of collision to minimal values, especially after speed reduction. The USACE and Canadian methods, despite speed reduction, still show an increased risk of collision, indicating the need for additional safety measures such as widening the fairway or better traffic management. The results confirm that speed reduction significantly reduces collision risk, but for methods with narrower fairways it may not be sufficient, requiring further optimisation of the shipping infrastructure.

Despite the significant conclusions obtained, the studies carried out have some limitations. First of all, the empirical method used derives from a preliminary analysis of the issue, which includes environmental and operational constraints that may affect the accuracy of the estimates. In addition, dynamic variables, real-time weather conditions, which affect the dimensioning of the fairways, were not fully considered.

References

1. Artyszuk, J., Gralak, R., Gucma, M., Gucma, S., Ślączka, W., Zalewski, P. (2016). Optimization of waterway bend widths using computer simulation methods of ship movement. *Scientific Journals of the Maritime University of Szczecin*, *46(118),* pp. 115-121.
2. Baric, M., Mohovic, R., Mohovic, D. (2019). Determining restricted fairway additional width due to bank effect for fine form vessels. *The Journal of Navigation*, *72(6),* pp. 1435-1448. https://doi.org/10.1017/S0373463319000250
3. Chen, L., Zhang, Y., Wang, X., Li, J. (2023). Optimisation of fairway dimensions based on artificial intelligence. *Journal of Marine Science and Engineering*, *11(2),* p. 123. https://doi.org/10.3390/jmse11020123
4. Emery, B.E. (2024). Fair and reasonable: A conceptual insight into USACE dredge estimating. *Journal of Waterway, Port, Coastal, and Ocean Engineering*.
5. Forecasts of the Szczecin-Świnoujście Port Authority.
6. Gucma, S., Gralak, R., Przywarty, M. (2022). Generalized method for determining the width of a safe maneuvering area for bulk carriers at waterway bends. *Sustainability*, *14(11),* p. 6706. https://doi.org/10.3390/su14116706

7. Gucma, S., Gralak, R., Jesion, P., Łempicki, M., Przywarty, M. (2021). Safety analysis of ship operation on the rebuilt Świnoujście-Szczecin waterway. *Marine Engineering and Geotechnics*, *6*, pp. 230-236.
8. Gucma, S., Kotowska, I., Ślączka, W. (2016). Wybór lokalizacji terminalu kontenerowego w Świnoujściu. *Inżynieria morska i geotechnika*.
9. Gucma, S., Przywarty, M. (2020). Kinematic method of determining safe fairway bend widths. *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation*, *14(2),* pp. 431-436. https://doi.org/10.12716/1001.14.02.22
10. Gucma, S., Ślączka, W. (2017). Risk analysis of ship manoeuvring in the design process of marine waterways and ports. *Marine Engineering and Geotechnics*, *6*, pp. 316-324.
11. He, J., Li, K., Zhang, W. (2022). Dynamic yard allocation for an automated container terminal. *Annals of Operations Research*, *343*, pp. 927-948. https://doi.org/10.1007/s10479-021-04458-6
12. Kastner, M., Bausch, L., Hartmann, S. (2023). About estimating the required yard capacity for container terminals. *Proceedings of the 2023 International Conference on Logistics and Maritime Systems*. https://doi.org/10.1007/978-3-031-56826-8_13
13. Khorram, S. (2020). A novel approach for ports' container terminals' risk management based on formal safety assessment: FAHP-entropy measure-VIKOR model. *Natural Hazards*, *103(2),* pp. 1709-1728. https://doi.org/10.1007/s11069-020-03976-z
14. Liu, Z., Chen, Y., Yang, Z. (2024). Modelling and analysing stacking strategies in automated container terminals. *Transportation Research Part E: Logistics and Transportation Review*, *164*, p. 103220. https://doi.org/10.1016/j.tre.2024.103220
15. Mankiw, N.G. (2020). *Principles of Economics*. Boston: Cengage Learning.
16. MarineTraffic.
17. Maritime Authority hydrographic reports, AIS data.
18. Ministry of Infrastructure (2023). *Development of seaports in Poland*.
19. Montewka, J., Przywarty, M. (2005). Mathematical modelling methods used to describe the position of a ship and to determine the lane width based on two non-simultaneous laser rangefinder measurements. *Polish Journal of Navigation*, *4*, pp. 45-52.
20. Orymowska, J., Sobkowicz, P., Ślączka, W. (2015). Comparative analysis of methods for determining the lane width of an inland ship on a rectilinear section. *Technika Transportu Szynowego*, *22(12),* pp. 223-230.
21. Pallis, A.A. (2017). *Port Risk Management in Container Terminals*. Inter-American Committee on Ports, pp. 1-15.
22. PIANC (2014). *Access Channels to Ports – Design Guidelines*.
23. PIANC (2014). *Guidelines for the Design of Safe and Efficient Navigation Channels*. Brussels: PIANC International.
24. PIANC (2020). *Resilience in Maritime and Inland Waterway Transport*. Brussels: PIANC International.

25. Przywarty, M., Gucma, S., Dzwonkowski, J. (2020). Kinematic method for determining the safe bend widths of waterways. *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation*, *14(2),* pp. 435-442. https://doi.org/10.12716/1001.14.02.20
26. Rodrigue, J.-P. (2025). Systemic analysis of container terminal layouts. *Journal of Shipping and Trade, 10(1),* p. 4. https://doi.org/10.1186/s41072-025-00194-3
27. Szczecin-Świnoujście Port Authority reports.
28. USACE (2006). *Hydraulic Design of Deep-Draft Navigation Projects*. Washington, DC: U.S. Army Corps of Engineers.
29. USACE (2018). *Coastal Engineering Manual*. Washington, DC: U.S. Army Corps of Engineers.
30. Wang, Y., Li, X., Zhou, P., Chen, H. (2019). Simulation-based approaches for ship maneuvering in constrained waterways. *Ocean Engineering*, *182*, p. 102118. https://doi.org/10.1016/j.oceaneng.2019.102118
31. Zalewski, P. (2012). Algorithms for analytical method of waterway design parameters determination. *Scientific Journals of the Maritime University of Szczecin*, *32(104),* pp. 101-106.

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CORPORATE SOCIAL RESPONSIBILITY AND GREEN HUMAN RESOURCE MANAGEMENT: INSIGHTS FROM A BIBLIOMETRIC ANALYSIS OF SCIENTIFIC LITERATURE

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Purpose: Identification of the main areas of research addressed in scientific publications that also relate to Corporate Social Responsibility (CSR) and Green Human Resource Management (GHRM).
Design/methodology/approach: The study was designed and conducted between December 2024 and May 2025. It was based on a systematic review of the literature. Two bibliometric queries were constructed to explore the Scopus database (Q1) and the Web of Science database (Q2). The bibliometric analysis was performed on the author's keywords assigned to 92 selected scientific publications, from which the main areas of research were extracted using the VOSviewer software.
Findings: Thirteen main areas of research addressed in scientific publications that also relate to CSR and GHRM were identified. Apart from CSR and GHRM, researchers most often referred to issues such as sustainability, environmental performance and green innovation.
Research limitations/implications: The main limitations of the study include the author's own bibliometric queries (Q1 and Q2) and the restriction of the selection of scientific publications to two databases (Scopus and Web of Science). These limitations also allow the study to be repeated in the future to identify changes and compare the study with other bibliometric analyses focused on CSR and/or GHRM.
Originality/value: The analyses conducted stand out from previous bibliometric studies focused on CSR and/or GHRM in terms of the content of bibliometric queries. During the analysis, numerous research implications and practical applications for business were outlined. In addition, potential future directions for research on CSR and GHRM were identified, including various issues related to green jobs. The article is intended for those interested in CSR and GHRM.
Keywords: corporate social responsibility, green economy, green human resource management, green innovation, green jobs, sustainability.
Category of the paper: Literature review.

1. Introduction

The socio-economic reality is constantly changing under the influence of various social, economic and environmental factors. Numerous researchers recognise the significant direct and indirect impact of individual enterprises (e.g. Aversa, 2024; Di Febo, Angelini, 2025) and entire sectors of the economy (e.g. Iamkovaia et al., 2019; Rehman et al., 2021) on adverse climate change. Scientific research is also increasingly recognising the impact of climate change on the functioning of individual enterprises (e.g. Morales et al., 2022; Sanderson et al., 2019), sectors (e.g. Christine Li et al., 2025; Olarewaju, Ganiyu, 2021; Wakweya, 2025) and economies (e.g. Davydenko et al., 2021). It is pointed out in the case of direct impact that this may manifest itself in various ways, including supply chain disruptions caused by extreme weather events such as floods (e.g. Ghadge et al., 2020). On the other hand, the most frequently mentioned factor when it comes to the indirect impact of climate change on enterprises is increased pressure from stakeholders (e.g. Peter, 2023) to develop sustainable strategies and implement green practices in daily operations. Investors, the local community operating in the vicinity of a given enterprise, and consumers occupy a special place among these stakeholders. In the last group of stakeholders mentioned above, researchers discussing the green transition increasingly distinguish so-called green consumers (e.g. Boota et al., 2025; Goyal, Goyal, 2021; Paduszyńska, Kozar, 2024).

The increased pressure from stakeholders to improve the environmental performance of various business processes is widely recognised. At the same time, enterprises are expected to not only meet the formal and legal requirements specific to their business, but also to invest in ensuring significantly higher environmental standards than the minimum required. This is understandable, given that various types of discussions (including scientific ones) increasingly emphasise the need for enterprises to commit to sustainable development, offering potential solutions to promote this approach (e.g. Bai et al., 2024; Yang et al., 2024). There is also growing public awareness of the need to promote sustainable development (e.g. Angelone et al., 2025). The adoption of a sustainable development path has the potential to curtail, and potentially even arrest, the deleterious climate change that is currently occurring. Some researchers go further, directly pointing to the need for a green transition (e.g. Huy, Phuc, 2025; Krasin, 2025; B. Li et al., 2025) or green transformation (e.g. Kozar, Sulich, 2023; Peng et al., 2022) of enterprises and entire economies. Consequently, scientific discourse is increasingly addressing the issues of the green economy (e.g. Maesaroh et al., 2024; Mo et al., 2024), green enterprises (e.g. Wang et al., 2023), and green entrepreneurship (e.g. Mondal, Singh, 2023; Singh et al., 2025).

In some enterprises, as practice shows, various types of activities are initiated voluntarily, which simultaneously take into account the environmental interests of individual stakeholders. These entities are acutely aware of the necessity for enterprises to conduct their business

activities in a responsible manner. This responsibility underscores the necessity for a comprehensive evaluation of all actions undertaken in the context of business operations, with a view to ascertaining their environmental impact prior to their initiation. Such actions are considered to be part of the concept of Corporate Social Responsibility (CSR) (e.g. Ivanaj et al., 2021; Ribeiro et al., 2024; Sharma et al., 2022). In enterprises, the execution of CSR activities is undertaken by a variety of organisational units. In some entities, predominantly large enterprises, a separate CSR department can be identified within their organisational structures (e.g. Risi et al., 2023; Youm et al., 2024).

Issues related to the implementation and development of CSR concepts are an area of interest for numerous researchers (Rani et al., 2025). It can be observed that, depending on the strategy adopted by an enterprise towards CSR, activities aimed at this goal take the form of passive or active engagement (Johnstone, 2018). In certain enterprises, CSR is considered to be merely a component of their image strategy. In such cases, enterprises undertake various types of activities, most often through passive forms of social engagement. Examples of such activities, which are aimed at both environmental issues and CSR, include the declarative adoption of Environmental, Social, and Governance (ESG) standards without their implementation in the enterprise's practice, or the sponsorship of various events aimed at raising green awareness among the public without the active involvement of employees. CSR can also be regarded as a significant component of strategic business management (Deepalakshmi et al., 2019). In this context, CSR is a pivotal factor in enhancing the value of an organisation, as it encompasses activities that are integrated with the long-term goals of the enterprise. The occurrence of this phenomenon is contingent upon the voluntary participation of individual employees in a range of CSR initiatives. Enterprises can, of course, encourage their employees to undertake various CSR activities, e.g. by allowing them to volunteer during working hours or by jointly planning and selecting individual initiatives. It is noteworthy that researchers are increasingly suggesting that CSR may be superseded by ESG (Kaźmierczak, 2022; Oprescu, Marcu, 2024) on the grounds that it is more quantifiable or a consequence of regulatory obligations. Nevertheless, the authors of this article posit that such statements are too far-reaching, as some researchers have clearly indicated that ESG does not replace CSR, either in name or as a concept. These considerations emphasise that ESG was created as a subcategory of CSR (Hazen, 2021).

Undertaking sustainable (e.g. Anand et al., 2025; Kraft, 2016), pro-environmental (e.g. Herbuś, Ślusarczyk, 2012) or green (e.g. Kang, Kang, 2023; Cai Li et al., 2023) actions within the context of CSR requires enterprises, as noted by the authors of this article, not only to make specific investments for this purpose, but above all to build an efficient human resource management system. It is important to acknowledge the growing discourse in the relevant literature that extends beyond conventional human resource management to encompass sustainable human resource management (e.g. Siddique et al., 2024) and green human resource management (GHRM) (e.g. Faheem et al., 2023; Pooja, Bhavani, 2025). In the context of the

green transition of the economy, the role of GHRM in enterprises is particularly recognised, with the assertion that this approach to human resources integrates environmental protection principles into personnel management processes. As the authors of this article observe, GHRM has the capacity to support CSR, by increasing awareness of and commitment to green issues among employees, and by contributing to the establishment of working conditions that are in accordance with the principles of sustainable development. In light of the mounting significance of GHRM within the framework of CSR, this subject has been the focus of an analytical investigation in this article.

The identification of the main areas of research addressed in scientific publications that also refer to CSR and GHRM issues was adopted as the research aim. The study hypothesised that the primary research domains would be ascertained through a bibliometric analysis of author keywords assigned to diverse categories of scientific publications. The decision was taken to subject scientific publications indexed in two bibliometric databases, Scopus and Web of Science, to bibliometric analysis based on strictly defined substantive criteria (described in more detail in the 'Research methodology' section). The research planning procedure involved the utilisation of a classic literature review. A systematic literature review method was employed in actual research, thereby ensuring the repeatability of the study thanks to the constructed bibliometric queries. The VOSviewer software (version 1.6.20) was utilised to map the identified main areas of research.

The article is divided into four sections. The constituent sections of the article are logically interconnected, thereby constituting an integral component of the overall composition. The initial section of the article, entitled 'Introduction', provides a foundation for the subsequent discussion by offering a comprehensive overview of the pertinent literature on the subject. This section delineates the objective of the research and engages in a discourse on the research methodologies and instruments utilised to accomplish and examine the outcomes. The second part of the article is devoted to a detailed discussion of methodological issues related to the research conducted. It is imperative to acknowledge the significance of meticulous attention being accorded to individual research activities and the research schedule, the latter of which is methodically divided into four primary stages. The procedure is described in meticulous detail, ensuring that other researchers can replicate the study, for example for the purpose of future comparative analysis. The authors of the article posit that the comprehensive delineation of the research methodology ensures scientific transparency, a crucial aspect in scientific research. In the context of the analyses conducted, this may also facilitate comparison with other bibliometric analyses centred on CSR and/or GHRM. The penultimate section of the article focuses on presenting the research results in the form of identified main areas of research addressed in scientific publications that address the issues of CSR and GHRM. The scientific discussion outlined here delineates both methodological implications and those aimed at business practice that can strengthen the emergence of green business ecosystems. The final section of the article, i.e. the conclusion, summarises the discussion on CSR and GHRM.

This section also draws attention to the limitations that have been identified as a result of the analyses that have been carried out. Furthermore, future research directions at the intersection of CSR and GHRM are indicated, including the issue of creating high-quality green jobs.

2. Research methodology

The research activities that led to the results described later in this article were carried out between December 2024 and May 2025. As illustrated in Figure 1, a series of meticulously planned research activities were conducted during this period, which were methodically divided into four distinct stages of research. The sequence of research activities stipulated in the schedule was meticulously delineated, with two key objectives being paramount. The primary objective was to achieve the highest attainable standard of results. Secondly, the assumption was made that the study should be repeatable for the purpose of comparison with other bibliometric studies, both those already presented in various scientific publications and those to be carried out in the future on the issues of CSR and GHRM.

The initial stage of the research process, which focused on identifying the research problem, commenced with a review of selected scientific publications on CSR issues. The review encompassed solely scientific publications (articles, conference papers and reviews) indexed in two databases, Scopus and Web of Science. It was observed that within the domain of scientific research concentrated on CSR issues, there is an emerging interest among researchers in a range of subjects pertaining to the green transformation of the economy. In the context of the various green research issues that have been raised concerning CSR, it has been observed that GHRM is becoming an increasingly significant area of research. Concurrently, the literature review identified a paucity of bibliometric studies that would identify significant research areas addressed in scientific publications simultaneously referring to CSR and GHRM. This observation was the foundation upon which the research aim was formulated.

At the commencement of the second stage of the research, it was assumed that the aim of the research would be to identify the main areas of research addressed in scientific publications that also deal with CSR and GHRM issues. As in many previous bibliometric studies, the main areas of research in the designed study will be identified on the basis of an analysis of the authors' keywords. The authors of this article posit that these words constitute a synthetic presentation of the most important issues addressed in a given scientific publication. Two databases were selected for bibliometric analysis: Scopus and Web of Science. It is evident that both of these databases are extensively utilised for bibliometric analysis of CSR issues (e.g. Deng et al., 2024; Glavas, Visentin, 2024; Kargbo et al., 2025) and GHRM (e.g. Kamboj, 2024; Miah et al., 2024; Tahir et al., 2024).

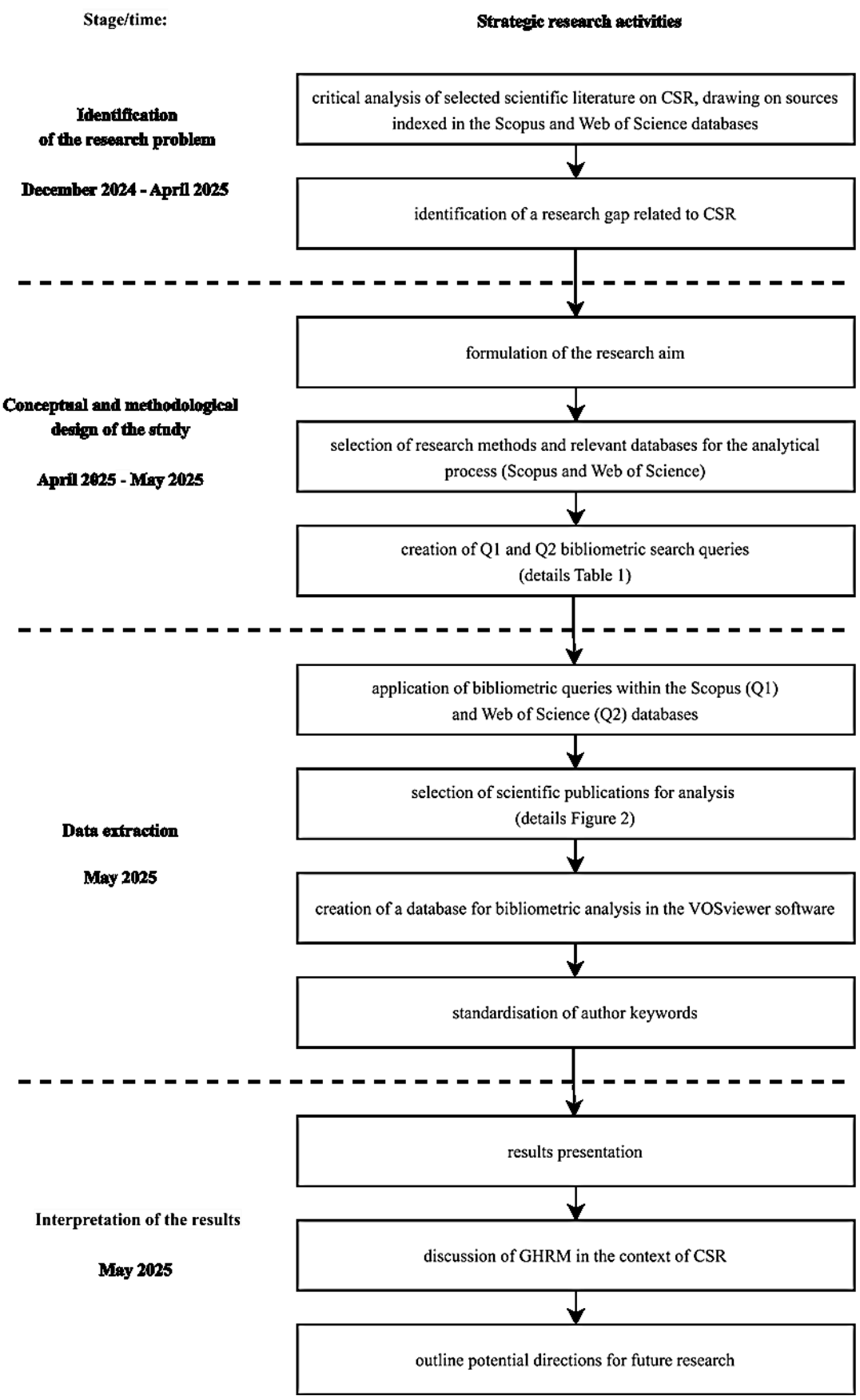

Figure 1. Research procedure stages and timeline.

Source: Authors' elaboration.

The Scopus and Web of Science databases facilitate the construction of bibliometric queries. This aspect facilitates the reproducibility of research that is based on these databases. Furthermore, in numerous scientific publications focused on bibliometric analyses, researchers emphasise that both the Scopus and Web of Science databases are not only recognised in the scientific world as reliable sources of information, but above all have strictly defined rules for indexing scientific journals in these databases (e.g. Ihsaniyati et al., 2023; Sulich, Kozar, 2023; Wodnicka, 2024). A further compelling rationale for opting for these two databases as sources for bibliometric analyses is that their content does not fully overlap. It is evident that the range of scientific publications selected on the basis of the same bibliometric query may exhibit a certain degree of overlap between the indicated databases. Nevertheless, as previous research practice shows, when exploring the Scopus or Web of Science databases with a given query, it is possible to extract publications assigned exclusively to one of these databases. Consequently, the final set of scientific publications incorporated in the bibliometric analyses, procured from both the Scopus and Web of Science databases, is more comprehensive. As a consequence, the analyses furnish a considerably more complete depiction of the subject under scrutiny than would be the case with a solitary database.

The final research activity conducted at the 'Conceptual and methodological design of the study' stage was the construction of two bibliometric queries. As demonstrated in Table 1, bibliometric query Q1 was formulated to explore the Scopus database, and bibliometric query Q2 was created to search the Web of Science database. Notwithstanding syntactic disparities, both queries facilitate the extraction of a set of scientific publications in English that pertain to both CSR and GHRM (the reference is made in the abstract and/or keywords and/or title). In both cases, publications that have been withdrawn for various reasons were not included in the analysis.

Table 1.
Details of search query syntax for Scopus databases

Database	Symbol	Query syntax	No. results
Scopus	Q1	TITLE-ABS-KEY (("green human resource management" AND "corporate social responsibilit*")) AND (LIMIT-TO (LANGUAGE, "English"))	99
Web of Science	Q2	((TS=("green human resource management" AND "corporate social responsibilit*")) AND LA=(English)) NOT DT=(Retracted Publication)	145

Source: Authors' elaboration 14.05.2025.

The penultimate stage of the research commenced with the implementation of bibliometric queries within the Scopus and Web of Science databases. In consequence of the execution of bibliometric query Q1, which was designed to facilitate exploration of the Scopus database, a total of 99 scientific publications were identified (comprising 76 articles, 10 book chapters, 10 reviews and 3 conference papers). In turn, query Q2, which explored the Web of Science database, allowed for the identification of 145 scientific publications (comprising 129 articles, 12 reviews and 4 proceeding papers).

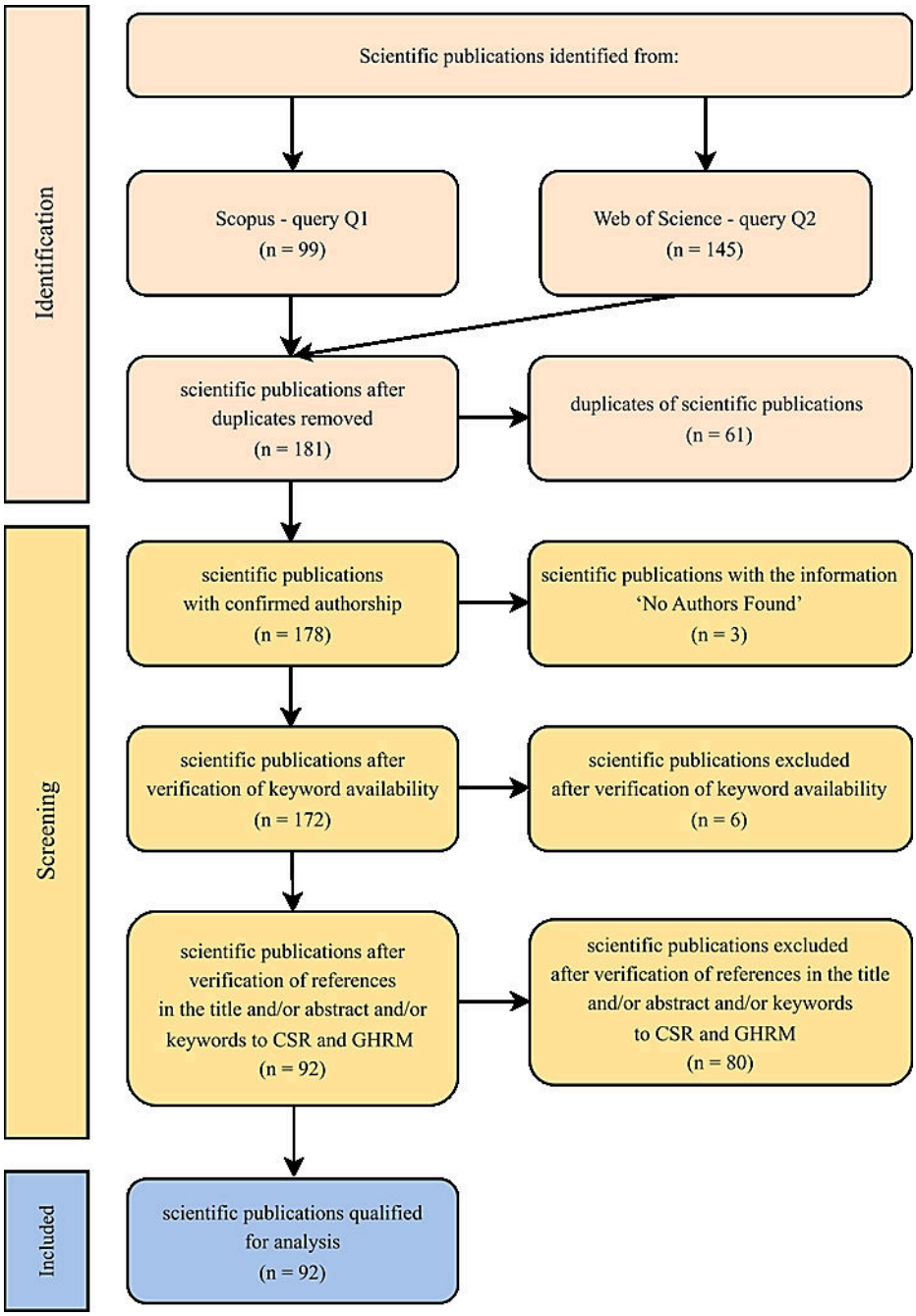

Figure 2. Procedure for the selection of scientific publications for analysis.

Source: Authors' elaboration.

Considering the previously mentioned issue that the scope of both explorations may overlap to some extent, a selection of scientific publications was made. The objective of this process was to eliminate from further analysis those scientific publications that are duplicates, for which no authors are assigned in the analysed databases, or for which author keywords are absent, as illustrated in Figure 2. Furthermore, scientific publications in which CSR and GHRM were absent from the title, abstract, and/or keywords were excluded from further analysis. This phenomenon could be attributed to the fact that bibliometric queries scoured a more extensive array of keywords than solely author keywords (in the case of the Scopus database, the query also searched indexed keywords, while in the case of the Web of Science database,

it searched keywords plus). The result of the scientific publication selection procedure was the selection of 92 publications for analysis (73 articles, 8 book chapters, 7 reviews, 4 conference papers/proceedings). The selected set of scientific publications was used both to achieve the research aim and to outline future research directions related to CSR and GHRM.

The final procedure conducted in the third stage of the research pertained to the standardisation of author keywords. The application of this procedure was necessitated by the requirement to achieve a high-quality bibliometric map. Standardisation has resulted in the unification of the forms of recording author keywords with equivalent meanings. Consequently, abbreviations were replaced with their full names (e.g. csr - corporate social responsibility; ghrm - green human resource management; ghr management - green human resource management), and a uniform form of singular or plural was adopted for a given research problem (e.g. corporate social responsibilities - corporate social responsibility). Consequently, the number of unique author keywords decreased from 275 to 247.

The results of the bibliometric analyses were presented and discussed at the culmination of the research. A comprehensive account of this stage can be found in the subsequent sections of this article. It should be noted that the results presented in this section were influenced by limitations inherent in the research, which could not be eliminated. This study utilised two bibliometric databases, Scopus and Web of Science, to analyse the data obtained. Consequently, conducting analyses based on a larger number of databases or on bibliometric databases that are entirely different may yield different results. Moreover, the configuration of the bibliometric queries imposed constraints on the search field. Nevertheless, the adopted detailed research methodology allows for both the repetition of the study in the future and the comparison of its results with other bibliometric studies on CSR and GHRM (both those already conducted and published in scientific papers and those to be carried out in the future). Therefore, the premises limiting the study are also important premises determining its quality.

3. Results and discussion

The bibliometric database obtained in the third stage of the research (detailed in the Research methodology section) was used to create a bibliometric map in VOSviewer software (version 1.6.20), which presents the main areas of research addressed in scientific publications that also deal with CSR and GHRM (Figure 3). The decision to utilise this specific software for bibliometric analysis was primarily influenced by three key factors. Firstly, this software is one of the most widely utilised in bibliometric analysis by numerous researchers dealing with CSR or GHRM issues. Secondly, it should be emphasised that VOSviewer software provides very high-quality visualisations (e.g. by allowing some of the analysed keywords to be excluded from the visualisation). Thirdly, the software facilitates the visualisation of bibliometric

connections between individual author keywords. From a technical perspective, the bibliometric map presented in Figure 3 was created by selecting the co-occurrence option (type of analysis), author keywords (unit of analysis) and full counting (counting method) from the map creation panel in VOSviewer. In the subsequent panel of the software, entitled 'choose threshold', the minimum number of occurrences of a keyword was set at 5, as indicated by the software. Fourteen author keywords satisfied this criterion. In the final panel preceding the creation of the bibliometric map (verify selected keywords), the author keyword 'bibliometric analysis' was excluded. Such exclusions are customary in bibliometric analyses and are intended to enhance the quality of the visualisation obtained. It has been demonstrated by means of empirical observation that the most frequently excluded keywords are those referring to research methods, types of visualisations, geographical names or, in some cases, the names of individual countries. The bibliometric map generation procedure described above resulted in 13 author keywords being included, which, as previously indicated, also constitute the main areas of research identified in scientific publications that address both CSR and GHRM issues.

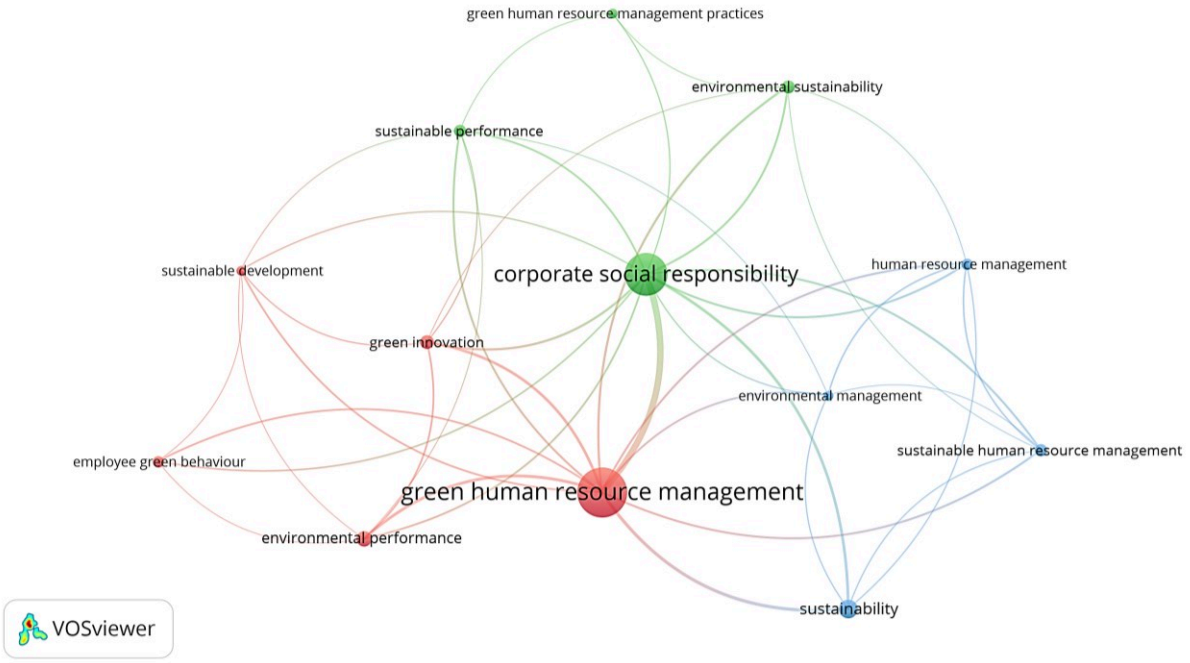

Figure 3. Bibliometric map of co-occurrence identifying key green research areas.

Source: Authors' elaboration in VOSviewer software (version 1.6.20).

The author's keywords in Figure 3 were assigned by the VOSviewer software to one of three clusters, which differ in colour (red, green, blue). It should also be noted that the author's keywords on the bibliometric map are marked as signed nodes. In addition, each node is characterised by two key bibliometric measures: occurrences and links. The occurrences measure determined the size of the node on the bibliometric map and also indicates the number of scientific publications (out of 92) in which a given research area was an author's keyword. When analysing this measure, it should be borne in mind that these are already author keywords after standardisation. The second measure, i.e. links, taking into account the type of bibliometric

map, shows with which visualised keywords the analysed main research area co-occurred as an author keyword. It should be noted here that the thicker the link between the identified main research areas on the bibliometric map, the more frequently these words co-occurred as author keywords. The values of the above-mentioned bibliometric measures assigned to the visualised author keywords on the bibliometric map are presented in Table 2.

Table 2.
The clusters generated with VOSviewer software and shown in Figure 3

Cluster	Keywords	Occurrences	Links
red	employee green behaviour*	6	4
	environmental performance	10	6
	green human resource management*	72	11
	green innovation	9	6
	sustainable development	5	6
green	corporate social responsibility*	56	12
	environmental sustainability	8	6
	green human resource management practices*	5	3
	sustainable performance	7	7
blue	environmental management	5	6
	human resource management*	6	6
	sustainability	14	5
	sustainable human resource management	6	7

*for these keywords, procedures were carried out to standardise the spelling of the author's keywords

Source: Authors' elaboration.

The bibliometric data presented in the table indicate that none of the identified main research areas appeared as an author keyword in all analysed scientific publications. The highest number of occurrences was recorded for green human resource management (red cluster), corporate social responsibility (green cluster) and sustainability (blue cluster). In the case of links, as further indicated in Figure 4, only corporate social responsibility (green cluster) co-occurred at least once with all visualised main research areas as an author keyword in the analysed set of scientific publications. The author keyword green human resource management (red cluster) also had a high number of links. This identified main research area was not exclusively related to green human resource management practices. It can be assumed that authors with limited space for author keywords referred either to GHRM or to GHRM practices. Two author keywords, sustainable performance and sustainable human resource management, ranked third in terms of links. It should be noted here that GHRM should not be equated with sustainable human resource management. The bibliometric analysis revealed that in some publications, these two issues appeared simultaneously as author keywords (e.g. Banga, Gobind, 2025; Gaurav et al., 2025; Mukherji, Bhatnagar, 2022). This aspect only confirms the ongoing scientific discourse highlighting the fundamental differences between GHRM and sustainable human resource management.

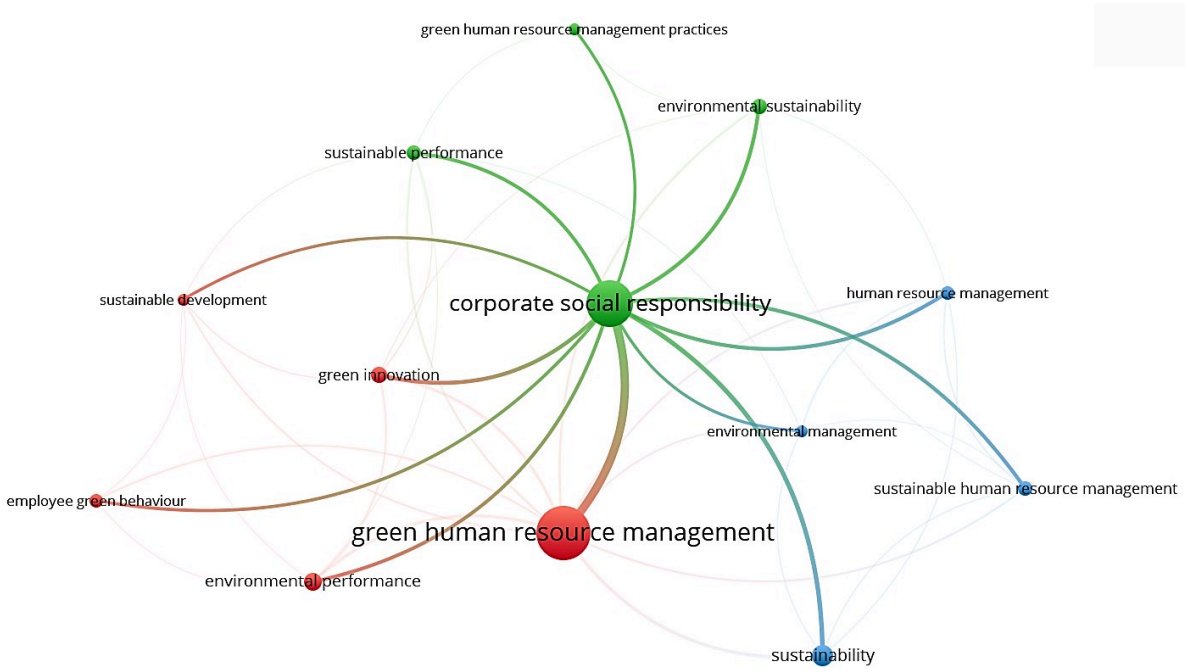

Figure 4. Visualization of connections with corporate social responsibility on a bibliometric map.
Source: Authors' elaboration in VOSviewer software (version 1.6.20).

The most frequently occurring author-provided keywords in the analysed scientific publications were GHRM and CSR (e.g. Fachada et al., 2022; Tiep Le et al., 2024; Yousaf et al., 2025). These publications referred to various research issues. A content analysis of these scientific publications revealed that, in the context of GHRM and CRS, numerous current important issues are being addressed, including ESG (e.g. Lee, Ahn, 2025; Papademetriou et al., 2023), or various green research issues such as green organisational culture (e.g. Cömert et al., 2025), green recruitment (e.g. Aytekin, 2021; Mishra, 2017), green selection (e.g. Cheema, Javed, 2017), green psychological climate (e.g. Gupta, Kaur, 2024; Sabokro et al., 2021), green psychosocial environment (e.g. Wei, 2023), green human capital (e.g. Sowmiya et al., 2024), and green value strategy (e.g. Mering, 2024).

The green research issues cited above are merely illustrative of the green research topics that have been addressed in the context of CSR and GHRM. In addition to the aforementioned, bibliometric maps (see Figures 3-4) demonstrate references to employee green behaviour (red cluster), green innovation (red cluster) and green human resource management practices (blue cluster). Research indicates the presence of intricate interrelationships between CSR and employee green behaviour, with GHRM acting as a mediating entity (Aukhoon et al., 2024b). It has been posited by certain researchers that CSR and GHRM are contextual factors which have the capacity to stimulate green behaviour among employees in the workplace (D. Zhou et al., 2023). As posited by some researchers, GHRM practices have been demonstrated to be a significant factor in the enhancement of the positive impact of CSR on green employee behaviour (Aukhoon et al., 2024a). In contemporary business enterprises that are committed to the pursuit of sustainable development, a diverse array of green innovations is being

implemented. Numerous scientific studies have identified this issue and emphasised the impact of green innovations on the environmental performance of enterprises (Niazi et al., 2023; S. Zhou et al., 2024) or even their green performance (Azam, Jamil, 2024).

In addition to green research issues, a significant number of issues related to sustainable development and the environment are highlighted in the bibliometric maps presented. For instance, the analysed articles refer to environmental sustainability (e.g. Mittal, Gupta, 2023; Wen et al., 2022) and environmental performance (e.g. Khan et al., 2024; Rana, Arya, 2024; Sun et al., 2024). It is evident that references to both sustainability (blue cluster) and sustainable development (red cluster) can also be found. The author's keywords were not unified at the standardisation stage, as the authors of this article note that subtle differences in meaning are increasingly being observed in scientific research between these research areas.

The bibliometric analysis, which forms the basis for the results presented above, also enabled the identification of significant implications arising from the research conducted to date, while referring to the issues of CSR and GHRM. Firstly, it was observed that there is a diversity of terms and definitions used for both CSR and GHRM. A significant number of researchers have created definitions that are tailored to the specific requirements of their respective studies. It is evident that these factors complicate the process of conducting a comparative analysis of the results obtained in disparate studies. It is therefore evident that there is a clear necessity to standardise the definitions employed for both CSR and GHRM. Another methodological implication that has been observed is the geographical and cultural limitation of the research. Individual researchers tend to concentrate on issues of CSR and GHRM in a given organisation or organisations operating within a strictly limited area (e.g. an administrative region or country). Concurrently, there is a conspicuous absence of research that makes comparisons between the same aspects in companies, for example from the same industry, but operating in different cultural contexts.

Among the implications for business practice arising from the bibliometric analysis, it should be noted that a significant proportion of researchers recognise that employees are more committed to their work if they believe that the enterprise operates in an ethical or environmentally friendly manner. Consequently, when implemented effectively within a company's operations, both CSR and GHRM can function as instruments to promote employee retention. Concurrently, new opportunities for recruitment are being created. For instance, it has been demonstrated that companies that employ GHRM practices are better positioned to attract young employees, who frequently possess green attitudes. For these employees, the presence of environmental values is a significant factor in determining the selection of a potential employer. It has been observed that the implementation of GHRM in conjunction with CSR can assist an enterprise in maintaining its competitive edge within a market characterised by mounting stakeholder expectations regarding environmental concerns. For instance, GHRM practices have the capacity to contribute to the establishment of a green image for a company within its business environment. Moreover, the integration of

CSR and GHRM has the potential to catalyse the emergence of green innovative solutions within a given company, manifesting, for instance, in the products and/or services offered. The authors of this article posit that CSR and GHRM practices can also stimulate the creation of a green business ecosystem in the market.

4. Summary

The study successfully achieved its intended aim. The analyses identified 13 main areas of research addressed in scientific publications related to both CSR and GHRM. The discussion also outlined important theoretical implications and those relevant to business practice. In comparison with other bibliometric analyses related to CSR and GHRM, the study distinguished itself not only in terms of the content of the bibliometric query, but also in terms of the research period and the implementation of two important research procedures, namely the selection of scientific publications and the standardisation of author keywords. The latter procedure, in particular, is not frequently employed by researchers, despite the fact that it significantly improves the quality of bibliometric maps.

The study identified the factors limiting its scope. Firstly, as previously stated, the primary constraint pertained to the utilisation of two specific databases: Scopus and Web of Science. Despite the fact that this limitation was founded upon quality considerations, it has the potential to result in the omission of publications that meet the criteria set out in the bibliometric query but are found in other databases. It is also noteworthy that the analysis did not encompass grey literature (e.g. industry reports on CSR and GHRM). The analysis exclusively encompassed English-language publications, a choice that undoubtedly contributed to the marginalisation of scientific achievements presented in other languages. A further limitation inherent to bibliometric methods is that, whilst they facilitate the identification of primary research domains – for instance, via the utilisation of author keywords – they nevertheless preclude the capacity to evaluate the methodological reliability of the analyses undertaken. It is also important to note that research of this type is dependent on the number of publications at the time of the analysis. Consequently, the results obtained on the primary research domains identified in accordance with the methodological assumptions should be interpreted in the context of the period during which the database for the analysis was generated. In this particular type of research, the results may become outdated due to the indexing of new scientific publications related to CSR and GHRM in the Scopus and/or Web of Science databases.

The analyses conducted enabled the observation of numerous green research issues raised in scientific publications referring to both CSR and GHRM. A significant green issue that is being addressed in a multitude of scientific studies pertaining to sustainable development and the green transition in various sectors of the economy is that of green jobs. The analysed set of

publications contains relatively few references to this issue. A review of the scientific publications included in the study reveals that the issue of green jobs in the context of CSR and GHRM was most extensively discussed in the research by Chouhan & Singh (2024). The authors of this article posit that the issue of green jobs has hitherto been the subject of inadequate analysis in the context of studies referring to both CSR and GHRM. This underscores the necessity for additional research in this domain. Firstly, it is imperative to initiate research on the impact of CSR and GHRM on the quality of green jobs created, including their degree of greening. It is also worth noting that while green HRMP practices are increasingly becoming a field of scientific analysis, there is still a lack of sufficient analysis of how such practices affect the professional development and job satisfaction of employees in the context of CSR. The exploration of the potential for integrating GHRM practices within the context of workplace greening initiatives is a subject that merits further investigation. Another potentially fruitful avenue for future research would be to explore the role and importance of green leaders in fostering an organisational culture that supports CSR and GHRM. The authors of this article posit that further research in the aforementioned green areas of research on CSR and GHRM is necessary, as it can provide new scientific knowledge that will support the development of theory and practice in the field of responsible and green organisation management. It is submitted that such research could also provide guidance on how to build sustainable green business ecosystems. Such research could also provide guidance on how to build sustainable green business ecosystems.

References

1. Anand, A., Sundaram, N., Sharma, A.K. (2025). Empathy in Action: Unravelling the Impact of Empathetic CSR on Sustainable Consumer Behavior through Customer-Company Identification. *International Journal of Computational and Experimental Science and Engineering*, *11*(2), 2225-2235. https://doi.org/10.22399/ijcesen.1541
2. Angelone, R., Marletta, A., Zenga, M. (2025). SDGs and Agenda 2030: Do Italians Really Know Them? In: A. Pollice, P. Mariani (Eds.), *Methodological and Applied Statistics and Demography II* (pp. 224-229). Cham: Springer. https://doi.org/10.1007/978-3-031-64350-7_39
3. Aukhoon, M.A., Iqbal, J., Parray, Z.A. (2024a). Impact of corporate social responsibility on employee green behavior: Role of green human resource management practices and employee green culture. *Corporate Social Responsibility and Environmental Management*, *31*(5), 3768-3778. https://doi.org/10.1002/csr.2773
4. Aukhoon, M.A., Iqbal, J., Parray, Z.A. (2024b). Corporate social responsibility supercharged: greening employee behavior through human resource management practices

and green culture. *Evidence-Based HRM: A Global Forum for Empirical Scholarship*, *12*(4), 945-965. https://doi.org/10.1108/EBHRM-11-2023-0312

5. Aversa, D. (2024). Scenario analysis and climate change: a literature review via text analytics. *British Food Journal*, *126*(1), 271-289. https://doi.org/10.1108/BFJ-08-2022-0691
6. Aytekin, I. (2021). Green Human Resource Management and Corporate Social Responsibility for a Sustainable Environment: A Bibliometric Review. *Contributions to Finance and Accounting: Vol. Part F212* (pp. 399-428). Springer Nature. https://doi.org/10.1007/978-3-030-72624-9_17
7. Azam, T., Jamil, K. (2024). Studying the role of corporate social responsibility, green HRM and green innovation to improve green performance of SMEs. *Journal of Business & Industrial Marketing*, *39*(12), 2620-2637. https://doi.org/10.1108/JBIM-02-2023-0087
8. Bai, F., Huang, Y., Zhang, Q., Shang, M. (2024). Unleashing the power of green culture: Exploring the path to sustainable development performance in enterprises. *Sustainable Development*, *32*(4), 3226-3247. https://doi.org/10.1002/sd.2831
9. Banga, C.M., Gobind, J. (2025). Implementation of sustainability in human resource management: A literature review. *SA Journal of Human Resource Management*, *23*. https://doi.org/10.4102/sajhrm.v23i0.2741
10. Boota, M., Ali, S., Khan, W.S., Ali, M. (2025). Can technology turn us green? Promoting green consumer behavior under the lens of norms activation theory. *Journal of Marketing Communications*, 1-23. https://doi.org/10.1080/13527266.2025.2465554
11. Cheema, S., Javed, F. (2017). The effects of corporate social responsibility toward green human resource management: The mediating role of sustainable environment. *Cogent Business & Management*, *4*(1), 1310012. https://doi.org/10.1080/23311975.2017.1310012
12. Chouhan, T., Singh, A. (2024). Green HRM: Redesigning Work and Green Job Structures for Organisational Sustainability. *Contemporary Studies in Economic and Financial Analysis, Vol. 114* (pp. 121-133). Emerald Publishing. https://doi.org/10.1108/S1569-375920240000114008
13. Cömert, P.N., Ozer, E., Gürol, Y., Akan, G., Bulgur, N.E. (2025). The green attraction: mediating role of environmental CSR and green HRM in the relationship between green culture and organizational attractiveness. *Management Research Review*, *48*(6), 966-990. https://doi.org/10.1108/MRR-05-2024-0360
14. Davydenko, N., Titenko, Z., Buriak, A., Polova, O. (2021). The impact of climate change on the investment attractiveness of agricultural enterprises. *IOP Conference Series: Earth and Environmental Science*, *915*(1), 012016. https://doi.org/10.1088/1755-1315/915/1/012016
15. Deepalakshmi, R., Shakthi Rishi, R.V., Kumar, M., Ruthran, B., Kathirvel. (2019). Global csr-a platform that connects the society with the corporates. *International Journal of Innovative Technology and Exploring Engineering*, *8*(6), 232-236.

16. Deng, Y., Ong, T.S., Senik, R. (2024). Trick or treat? A bibliometric literature review of corporate social responsibility and earnings management. *Corporate Social Responsibility and Environmental Management*, *31*(5), 4361-4383. https://doi.org/10.1002/csr.2806
17. Di Febo, E., Angelini, E. (2025). Transition Risk in Climate Change: A Literature Review. *Risks*, *13*(4), 66. https://doi.org/10.3390/risks13040066
18. Fachada, J., Rebelo, T., Lourenço, P., Dimas, I., Martins, H. (2022). Green Human Resource Management: A Bibliometric Analysis. *Administrative Sciences*, *12*(3), 95. https://doi.org/10.3390/admsci12030095
19. Faheem, A., Nawaz, Z., Ahmed, M., Haddad, H., Al-Ramahi, N.M. (2023). Past Trends and Future Directions in Green Human Resource Management and Green Innovation: A Bibliometric Analysis. *Sustainability*, *16*(1), 133. https://doi.org/10.3390/su16010133
20. Gaurav, A., Gupta, B.B., Attar, R.W., Arya, V., Alhomoud, A., Chen, M.-Y., Nedjah, N. (2025). Data-Driven Exploration of Emerging Trends in Sustainable Human Resource Management Using Advanced Analytics. *International Journal of Data Warehousing and Mining*, *21*(1), 1-15. https://doi.org/10.4018/IJDWM.368722
21. Ghadge, A., Wurtmann, H., Seuring, S. (2020). Managing climate change risks in global supply chains: a review and research agenda. *International Journal of Production Research*, *58*(1), 44-64. https://doi.org/10.1080/00207543.2019.1629670
22. Glavas, D., Visentin, G. (2024). CSR in times of crisis: a systematic literature review. *Management Review Quarterly*. https://doi.org/10.1007/s11301-024-00445-w
23. Goyal, M., Goyal, R.K. (2021). Confirming Antecedents of Green Consumption Intention: A Sustainable Model for Food Aggregators. *IETE Journal of Research*, *67*(5), 634-645. https://doi.org/10.1080/03772063.2021.1906336
24. Gupta, R., Kaur, S. (2024). A 2-1-1 multi-level perspective of understanding the relationship between green human resource management practices, green psychological climate, and green employee behavior. *Corporate Social Responsibility and Environmental Management*, *31*(5), 4068-4084. https://doi.org/10.1002/csr.2778
25. Hazen, T.L. (2021). Social Issues in the Spotlight: The Increasing Need to Improve Publicly-held Companies' CSR and ESG Disclosures. *University of Pennsylvania Journal of Business Law*, *23*(3), 740-796. https://heinonline.org/hol-cgi-bin/get_pdf.cgi?handle=hein.journals/upjlel23&section=21
26. Herbuś, A., Ślusarczyk, B. (2012). Zastosowanie koncepcji społecznej odpowiedzialności biznesu w zarządzaniu przedsiębiorstwem. *Polish Journal of Management Studies*, *6*, 234-240.
27. Huy, P.Q., Phuc, V.K. (2025). Changing times: does the critical success factors boosting green transition of SMEs remain unchanged? *Journal of Innovation and Entrepreneurship*, *14*(1), 2. https://doi.org/10.1186/s13731-024-00449-6
28. Iamkovaia, M., Arcila, M., Cardoso Martins, F., Izquierdo, A. (2019). Sustainable Development of Coastal Food Services. *Sustainability*, *11*(13), 3728.

https://doi.org/10.3390/su11133728
29. Ihsaniyati, H., Sarwoprasodjo, S., Muljono, P., Gandasari, D. (2023). The Use of Social Media for Development Communication and Social Change: A Review. *Sustainability*, *15*(3), 2283. https://doi.org/10.3390/su15032283
30. Ivanaj, S., Collet, M., Gendron, C., Friser, A. (2021). Lean and CSR, contradictions and complementarities: Toward an effective managerial solution. *Quality Management Journal*, *28*(4), 205-222. https://doi.org/10.1080/10686967.2021.1962775
31. Johnstone, L. (2018). Environmental management decisions in CSR-based accounting research. *Corporate Social Responsibility and Environmental Management*, *25*(6), 1212-1222. https://doi.org/10.1002/csr.1632
32. Kamboj, J.A.E. (2024). Mapping the green human resource management practices: A systematic scoping review and its implications for employees' well-being. *Human Systems Management*, *43*(6), 932-970. https://doi.org/10.3233/HSM-230183
33. Kang, E.Y., Kang, S.Y. (2023). Green CSR Communication to Internal Audiences: The Persuasive Power of Normative Appeals to Employees' Green Behaviors. *Journal of Current Issues & Research in Advertising*, *44*(4), 473-496. https://doi.org/10.1080/10641734.2023.2218449
34. Kargbo, U., Terrence, B., Palmer, T.B. (2025). Redefining Corporate Social Responsibility: The Role of Strategic Communication Practices. *Sustainability*, *17*(9), 4226. https://doi.org/10.3390/su17094226
35. Kaźmierczak, M. (2022). A literature review on the difference between CSR and ESG. *Scientific Papers of Silesian University of Technology. Organization and Management Series*, *162*, 275-289. https://doi.org/10.29119/1641-3466.2022.162.16
36. Khan, A.J., Hameed, W.U., Ahmed, T., Iqbal, J., Aplin, M.J., Leahy, S. (2024). Green Behaviors and Innovations: A Green HRM Perspective to Move from Traditional to Sustainable Environmental Performance. *Employee Responsibilities and Rights Journal*, *36*(2), 231-248. https://doi.org/10.1007/s10672-023-09443-8
37. Kozar, Ł.J., Sulich, A. (2023). Energy Sector's Green Transformation towards Sustainable Development: A Review and Future Directions. *Sustainability*, *15*(15), 11628. https://doi.org/10.3390/su151511628
38. Kraft, K. (2016). Corporate social responsibility activities by companies of the food industry. *Journal of the Austrian Society of Agricultural Economics*, *26*, 95-104. https://doi.org/10.24989/OEGA.JB.26.11
39. Krasin, M. (2025). Organizational prerequisites for the transition of companies towards a green economy. *Edelweiss Applied Science and Technology*, *9*(2), 1993-2004. https://doi.org/10.55214/25768484.v9i2.5006
40. Lee, D., Ahn, J.-Y. (2025). Unlocking the potential of green human resource management in Korea: a comprehensive review. *Asia Pacific Business Review*, *31*(1), 133-156. https://doi.org/10.1080/13602381.2024.2358945

41. Li, B., Rahman, M.M., Haneklaus, N., Li, S., Zhou, Y. (2025). Green transition initiatives to reduce environmental degradation: Adaptation, mitigation and synergistic effects. *Environmental Impact Assessment Review*, *115*, 107993. https://doi.org/10.1016/j.eiar.2025.107993
42. Li, Cai, Aziz, F., Asim, S., Shahzad, A., Khan, A. (2023). Employee green behavior: a study on the impact of corporate social responsibility (CSR) on employee green behavior, green culture: the moderating role of green innovation. *Environmental Science and Pollution Research*, *30*(48), 105489-105503. https://doi.org/10.1007/s11356-023-29798-7
43. Li, Christine, Camac, J., Robinson, A., Kompas, T. (2025). Predicting changes in agricultural yields under climate change scenarios and their implications for global food security. *Scientific Reports*, *15*(1), 2858. https://doi.org/10.1038/s41598-025-87047-y
44. Maesaroh, S.S., Rahayu, A., Ahman, E., Wibowo, L.A., Swardana, A. (2024). Green Economy Research Trends and Mapping in SMEs: A Bibliometric Analysis. *International Journal of Sustainable Development and Planning*, *19*(3), 1003-1014. https://doi.org/10.18280/ijsdp.190318
45. Mering, L. (2024). Analysis of Green HRM, Green Value Strategic Improving CSR and Green Performance in Central Kalimantan HSL Palm Companies. *International Review of Management and Marketing*, *14*(3), 113-122. https://doi.org/10.32479/irmm.16262
46. Miah, M., Szabó-Szentgróti, G., Walter, V. (2024). A systematic literature review on green human resource management (GHRM): an organizational sustainability perspective. *Cogent Business & Management*, *11*(1). https://doi.org/10.1080/23311975.2024.2371983
47. Mishra, P. (2017). Green human resource management. *International Journal of Organizational Analysis*, *25*(5), 762-788. https://doi.org/10.1108/IJOA-11-2016-1079
48. Mittal, P., Gupta, S. (2023). Green HRM: An innovative approach to sustainable organizations. *Green Management - A New Paradigm in the World of Business* (pp. 155-164). Nova Science Publishers, Inc.
49. Mo, R., Peng, X., Wang, S., Zhang, J.Z. (2024). Knowledge Mapping of Green Economy Research: A Bibliometric Analysis. *Sage Open*, *14*(4). https://doi.org/10.1177/21582440241293581
50. Mondal, S., Singh, S. (2023). A bibliometric and thematic analysis of green entrepreneurship in business research: current status and future research directions. *Environment, Development and Sustainability*, *27*(1), 67-139. https://doi.org/10.1007/s10668-023-03905-7
51. Morales, L.V., Robiglio, V., Baca, M., Bunn, C., Reyes, M. (2022). Planning for Adaptation: A System Approach to Understand the Value Chain's Role in Supporting Smallholder Coffee Farmers' Adaptive Capacity in Peru. *Frontiers in Climate*, *4*. https://doi.org/10.3389/fclim.2022.788369
52. Mukherji, A., Bhatnagar, J. (2022). Conceptualizing and theorizing green human resource management: a narrative review. *International Journal of Manpower*, *43*(3), 862-888.

https://doi.org/10.1108/IJM-06-2021-0376

53. Niazi, U.I., Nisar, Q.A., Nasir, N., Naz, S., Haider, S., Khan, W. (2023). Green HRM, green innovation and environmental performance: the role of green transformational leadership and green corporate social responsibility. *Environmental Science and Pollution Research*, *30*(15), 45353-45368. https://doi.org/10.1007/s11356-023-25442-6
54. Olarewaju, O.M., Ganiyu, I.O. (2021). Handbook of Research on Climate Change and the Sustainable Financial Sector. In: O.M. Olarewaju, I.O. Ganiyu (Eds.), *Handbook of Research on Climate Change and the Sustainable Financial Sector*. IGI Global. https://doi.org/10.4018/978-1-7998-7967-1
55. Oprescu, C., Marcu, M.-R. (2024). Exploring the ESG Surge: A Systematic Review of ESG and CSR Dynamics. *Review of International Comparative Management*, *Vol. 25, No. 2,* 229. https://doi.org/10.24818/RMCI.2024.2.229
56. Paduszyńska, M., Kozar, Ł.J. (2024). Consumer protection and sustainable development: key green research areas. *Ekonomia i Prawo*, *23*(2). https://doi.org/10.12775/EiP.2024.021
57. Papademetriou, C., Ragazou, K., Garefalakis, A., Passas, I. (2023). Green Human Resource Management: Mapping the Research Trends for Sustainable and Agile Human Resources in SMEs. *Sustainability*, *15*(7), 5636. https://doi.org/10.3390/su15075636
58. Peng, C., Jia, X., Zou, Y. (2022). Does digitalization drive corporate green transformation?—Based on evidence from Chinese listed companies. *Frontiers in Environmental Science*, *10*. https://doi.org/10.3389/fenvs.2022.963878
59. Peter, A. (2023). Climate Change and Supply Chain Arbitrations: Impact of EU Law on the BRI and Non-EU Entities. *Arbitration: The International Journal of Arbitration, Mediation and Dispute Management*, *89(4),* 437-485. https://doi.org/10.54648/AMDM2023028
60. Pooja, S., Bhavani, J. (2025). Bibliometric analysis of research trends in Green Human Resource Management and sustainable development. *International Journal of Human Capital in Urban Management, Vol. 10, Iss. 1*, pp. 179-198. Tehran Urban Research and Planning Center. https://doi.org/10.22034/IJHCUM.2025.01.12
61. Rana, G., Arya, V. (2024). Green human resource management and environmental performance: mediating role of green innovation – a study from an emerging country. *Foresight*, *26*(1), 35-58. https://doi.org/10.1108/FS-04-2021-0094
62. Rani, R., Vasishta, P., Singla, A., Tanwar, N. (2025). Mapping ESG and CSR literature: a bibliometric study of research trends and emerging themes. *International Journal of Law and Management*. https://doi.org/10.1108/IJLMA-09-2024-0301
63. Rehman, A., Ullah, I., Afridi, F. e. A., Ullah, Z., Zeeshan, M., Hussain, A., Rahman, H.U. (2021). Adoption of green banking practices and environmental performance in Pakistan: a demonstration of structural equation modelling. *Environment, Development and Sustainability*, *23*(9), 13200-13220. https://doi.org/10.1007/s10668-020-01206-x
64. Ribeiro, L., Branco, M.C., Chaves, C. (2024). Evaluating the UN Global Compact Communication on Progress as a CSR Benchmarking Tool. *Systems*, *12*(5), 146.

https://doi.org/10.3390/systems12050146

65. Risi, D., Wickert, C., Ramus, T. (2023). Coordinated Enactment: How Organizational Departments Work Together to Implement CSR. *Business & Society*, *62*(4), 745-786. https://doi.org/10.1177/00076503221110213
66. Sabokro, M., Masud, M.M., Kayedian, A. (2021). The effect of green human resources management on corporate social responsibility, green psychological climate and employees' green behavior. *Journal of Cleaner Production*, *313*, 127963. https://doi.org/10.1016/j.jclepro.2021.127963
67. Sanderson, H., Irato, D.M., Cerezo, N.P., Duel, H., Faria, P., Torres, E.F. (2019). How do climate risks affect corporations and how could they address these risks? *SN Applied Sciences*, *1*(12), 1720. https://doi.org/10.1007/s42452-019-1725-4
68. Sharma, A., Kaushik, K., Awasthy, P., Gawande, A. (2022). Leveraging Text Mining for Trend Analysis and Comparison of Sustainability Reports: Evidence from Fortune 500 Companies. *American Business Review*, *25*(2), 416-438. https://doi.org/10.37625/abr.25.2.416-438
69. Siddique, N., Naveed, S., Inam, A. (2024). A bibliometric review on sustainable human resource management (1982-2023). *Journal of Organizational Effectiveness, Vol. 12, Iss. 1,* pp. 14-36). Emerald Publishing. https://doi.org/10.1108/JOEPP-09-2023-0432
70. Singh, H., Kumar, P., Dana, L.P. (2025). The green entrepreneurship landscape: drivers, outcomes, and future directions. *International Entrepreneurship and Management Journal*, *21*(1), 80. https://doi.org/10.1007/s11365-025-01079-4
71. Sowmiya, M., Poornima, A., Harish, M., Vaishnavi, S., Anto Pravin Singh, D., Prakash, K. (2024). The Impact of Green Human Resource Management on Sustainable Performance in the Indian IT Sector: Exploring the Mediating Role of Green Human Capital. *Pakistan Journal of Life and Social Sciences*, *22*(2), 12443-12458. https://doi.org/10.57239/PJLSS-2024-22.2.00890
72. Sulich, A., Kozar, Ł.J. (2023). Wearables and Sustainable Development: Exploring Future Implications for the Green Jobs and Green Labor Market. *Procedia Computer Science*, *225*, 279–288. https://doi.org/10.1016/j.procs.2023.10.012
73. Sun, J., Bhutta, M.K., Sarfraz, M. (2024). Green business in the digital age: sustainable performance in an era of technological advancement and leadership transformation. *Current Psychology*, *43*(41), 32168-32187. https://doi.org/10.1007/s12144-024-06723-w
74. Tahir, A.H., Umer, M., Nauman, S., Abbass, K., Song, H. (2024). Sustainable development goals and green human resource management: A comprehensive review of environmental performance. *Journal of Environmental Management*, *370*, 122495. https://doi.org/10.1016/j.jenvman.2024.122495
75. Tiep Le, T., Vu Nguyen Thao, L., Le, C.G.L., Bui Hai, T. (2024). Green human resource management and corporate social responsibility as drivers of organizational performance: mediating effects of employee engagement and corporate reputation in Vietnam. *Journal of*

Global Responsibility. https://doi.org/10.1108/JGR-02-2024-0023

76. Wakweya, R.B. (2025). Impacts of climate change on crop production and food security in Ethiopia. *Discover Sustainability*, *6*(1), 158. https://doi.org/10.1007/s43621-025-00830-9
77. Wang, N., Tang, G., Jiang, B., He, Z., He, Q. (2023). The development of green enterprises: A literature review based on VOSviewer and Pajek. *Australian Journal of Management*, *48*(2), 204-234. https://doi.org/10.1177/03128962211035470
78. Wei, X. (2023). Sustainability metrics of environmental sustainability in Iranian manufacturing sector: achieving through human resources. *Environmental Science and Pollution Research*, *30*(56), 118352-118365. https://doi.org/10.1007/s11356-023-30583-9
79. Wen, J., Hussain, H., Waheed, J., Ali, W., Jamil, I. (2022). Pathway toward environmental sustainability: mediating role of corporate social responsibility in green human resource management practices in small and medium enterprises. *International Journal of Manpower*, *43*(3), 701-718. https://doi.org/10.1108/IJM-01-2020-0013
80. Wodnicka, M. (2024). Skills Gap and New Technologies: Bibliometric Analysis. *Procedia Computer Science*, *246*(C), 3430-3436. https://doi.org/10.1016/j.procs.2024.09.214
81. Yang, X., Xu, Y., Hossain, M.E., Ran, Q., Haseeb, M. (2024). The path to sustainable development: exploring the impact of digitization on industrial enterprises' green transformation in China. *Clean Technologies and Environmental Policy*. https://doi.org/10.1007/s10098-024-03013-8
82. Youm, Y.N., Lee, J.Y., Lee, C.K. (2024). The effect of prosocial orientation on CSR scope: the moderating role of the CSR department. *Social Responsibility Journal*, *20*(4), 629-646. https://doi.org/10.1108/SRJ-01-2023-0024
83. Yousaf, H.Q., Munawar, S., Ahmed, M., Rehman, S. (2025). Environmental culture, green human resource management, green innovation, and environmental performance: the moderating role of corporate social responsibility. *Journal of Environmental Planning and Management*, *68*(8), 1858-1880. https://doi.org/10.1080/09640568.2023.2298263
84. Zhou, D., Lu, S., Zhou, J., Lu, J. (2023). *How to stimulate employee green behavior at workplace: based on a qualitative research method*, 84. https://doi.org/10.1117/12.3005427
85. Zhou, S., Tiruneh, W.A., Legese, M.A. (2024). The effect of corporate social responsibility on environmental performance: the mediating role of green innovation and green human resource management. *International Journal of Emerging Markets*, *19*(11), 3848-3868. https://doi.org/10.1108/IJOEM-02-2022-0211

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THE IMPACT OF WEBSITE INFORMATION LABELLING ON INFORMATION QUALITY ON THE WORLD WIDE WEB

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Purpose: Identification of the potential impact of informational labels used on websites on information quality, with particular emphasis on their semantic and syntactic characteristics.
Methodology: The study was conducted based on a comparative analysis of informational labels (contextual links, headings, navigation system elements, index terms) on websites from three sectors: public services (gov.pl), e-commerce (allegro.pl), and education (uni.opole.pl). For each type of label, semantic and syntactic features were determined, as well as their influence on selected information quality criteria.
Findings: Key semantic characteristics (unambiguity, relevance, contextuality) and syntactic characteristics (hierarchy, formatting, stylistic consistency) of informational labels were identified. Their impact on such information quality characteristics as accessibility, consistency, timeliness, relevance, completeness, and usability was demonstrated. The highest level of information quality is achieved through the synergistic combination of precise semantics with an appropriate presentation structure. The identified information quality characteristics on websites are consistent with universal models, which confirms their validity in design practice.
Research limitations: Limiting the analysis to three sectors (public services, e-commerce, education) narrows the possibility of fully generalizing the results. Further research requires an in-depth analysis of the impact of labels on user experience in different cultural and linguistic contexts.
Practical implications: The study indicates the necessity of systematic auditing and optimization of labelling systems as part of a comprehensive information quality management strategy for websites. It is important to maintain semantic and syntactic consistency of labels throughout the system and to adapt them to the needs of users.
Originality/value: This publication provides a comprehensive analysis of the impact of informational labels on information quality on websites, combining the perspective of information architecture with quality management. The work is addressed to both practitioners designing websites and theorists dealing with information quality in the digital environment.
Keywords: informational labels, information quality, information architecture, websites, information management.
Category of the paper: research paper.

1. Introduction

In the academic literature, the concept of information labelling appears across numerous scientific disciplines. Within the domain of information quality management, M.J. Eppler (2006, p. 368) defines labelling as: "Adding informative and concise titles to information items so that they can be more easily scanned, browsed, or checked for relevance. Labels should indicate the type of information (e.g., definition, example, rule) and its content (e.g., safety issues)". Contemporary research confirms the pivotal role of labelling systems in various digital contexts. L. Chen and H. Miyake (2021) demonstrated that labels based on hierarchical semantics significantly improve the efficiency of product categorization in e-commerce. Meanwhile, H. Ghalavand and A. Nabiolahi (2024) identified key criteria for health information quality on social media, such as credibility, timeliness, completeness, transparency, comprehensibility, accessibility, and usability. These proposed criteria align with the functions of labels. Credibility ranked second, which in practical terms translates to the use of precise informational labels for source evaluation. In a technical context, M. Krzesaj (2022) documented the implementation of tools and auto-verification mechanisms for labels (e.g., metadata tags, sitemaps), which enhance, among other aspects, the completeness of information on websites. The National Institute of Standards and Technology (NIST, 2022) emphasizes the growing importance of standardizing cybersecurity labels as a component of building user trust in software.

In the context of enhancing information quality within organizations, informational labels function as metadata describing the characteristics of information – an essential prerequisite for ensuring its transparency, credibility, and usability. M.J. Eppler identifies labels as one of the instruments of information integration, constituting an element of a broader information quality assessment system. Assigning labels to information objects primarily serves a signaling and defining role, specifying their meaning, type, and facilitating rapid access to a given content fragment. Labels may take the form of document headings, article tables of contents, or defined entries (such as names of chapters or subchapters). They significantly minimize the time required to analyze content, the meaning of which may be important from the perspective of a potential information consumer and their needs, for example, the subject of an email message or an entry defined in an online encyclopedia.

The principles of labelling, involving the skillful selection of appropriate substitutes for an information object, were described and applied in the concept of Information Mapping by R.E. Horn (1989). Horn presented the concept of Information Mapping, which constitutes a comprehensive approach to information structuring and is closely related to such fields as information visualization, information architecture, graphic design, information design, and data analysis. With the advancement of information technologies, this method has found application in user experience design, graphical interfaces, and knowledge management

systems. The methodology emphasizes recipient needs, content structuring, and logical organization of information by dividing content into smaller, more digestible blocks and their hierarchical arrangement. The method involves breaking information into small, easily assimilated parts. Each part is then assigned a clear, descriptive label, ensuring that each segment contains only essential information (relevance), which maintains uniform structure and format throughout the information object (consistency).

In the process of website design, labelling – according to L. Rosenfeld, P. Mougille and J. Arango (2017, pp. 79-80) – constitutes one of the four subsystems of information architecture: the information organization system, the labelling system, the navigation system, and the search system. These form the key elements of information architecture in website development. Effective organization, labelling, navigation, and search functions support the fulfillment of user needs, help to understand context, and facilitate efficient movement within the system. The information organization system creates logical structures that hierarchize data to increase their accessibility and comprehensibility for users – a crucial element of architecture that improves orientation within the system. The labelling system uses precise descriptors assigned to content elements to identify, categorize, and aid navigation. The navigation system includes menus, links, navigation buttons, and other elements that facilitate movement between sections of the website. The final element is the search system, which eliminates the need for manual browsing of complex structures, optimizing access paths to specific resources. Effective search is vital when users seek specific information without the need to browse the entire system structure.

Within information architecture, information quality plays a fundamental role in the functionality of a website. The literature identifies several common characteristic of information quality that are repeatedly highlighted by leading researchers in this field. The most frequently cited include: accessibility, completeness, timeliness, comprehensibility, consistency, unambiguity, relevance, and usability. Table 1 presents the definitions of these characteristics along with their authors.

Table 1.
Key Characteristics of Information Quality: Definitions and Theoretical Model Authors

Information Quality Characteristic	Definition	Key Authors
Accessibility	Information easily accessible to the user, critical for both producers and consumers.	Kahn, Strong, Wang (2002); Eppler (2006); Gupta (2000)
Completeness	Contains all necessary data to accomplish a task.	Kahn, Strong, Wang (2002); English (1999); Stvilia et al. (2007)
Currency/Timeliness	Regularly updated, impacting usability and decision-making accuracy.	Kahn, Strong, Wang (2002); Floridi (1999); Stvilia et al. (2007); Eppler (2006)
Understandability	Communicated in a clear and legible manner.	Kahn, Strong, Wang (2002); Eppler (2006); Stvilia et al. (2007)
Consistency	Free of contradictions, with logically interconnected elements.	Kahn, Strong, Wang (2002); English (1999); Stvilia et al. (2007); Eppler (2006)

Cont. table 1.

Unambiguity	Interpreted in a single way, without risk of misinterpretation.	Kahn, Strong, Wang (2002); Eppler (2006); Stvilia et al. (2007)
Relevance	Aligned with user needs and task context.	Kahn, Strong, Wang (2002); Floridi (1999); Stvilia et al. (2007); Gupta (2000); Eppler (2006)
Usability	Supports user goals and is easy to apply in practice.	Eppler (2006); Kahn, Strong, Wang (2002); Gupta (2000)

Source: own elaboration.

The presented characteristics are considered key in most contemporary models of information quality and form the basis for evaluating information in both information systems and websites. Recent studies also emphasize the importance of systematically improving information quality on websites through the use of specialized tools that directly influence these characteristics (Krzesaj, 2022). M. Krzesaj (2024) demonstrated the significant impact of organizational schemes (alphabetical, chronological, geographical, thematic, task-based, and hybrid) on eleven key information quality attributes. However, despite the documented importance of information organization systems, a significant research gap remains regarding the influence of labelling systems – one of the four fundamental subsystems of information architecture – on the quality of presented content. This gap is particularly evident in the context of analyzing the semantic and syntactic properties of informational labels and their specific impact on individual information quality characteristics in the online environment. In light of this identified research gap, the following research questions were formulated:

- What semantic and syntactic characteristics define different types of informational labels (contextual links, headings, navigation system elements, index terms) on websites?
- How do the identified semantic and syntactic characteristics of informational labels influence specific information quality criteria?
- Are there differences in the characteristics of informational labels across sectors (public services, e-commerce, education), and what are their causes?
- Which characteristics of informational labels have the strongest impact on key information quality attributes in the online environment?

The aim of the study is to identify the impact of informational labels used on websites on information quality, with particular emphasis on their semantic and syntactic characteristics. Each type of label was characterized in terms of its semantic and syntactic attributes, and its influence on selected criteria for assessing information quality was examined. The identified characteristics do not constitute a closed set. To achieve the research objective, a comparative analysis method of informational labels based on a qualitative approach was employed. The choice of this method was driven by the need to deeply understand the relationships between label characteristics and information quality, which required detailed contextual and semantic analysis. The study was conducted in three stages:

- Identification and categorization of labels on selected websites.
- Analysis of semantic and syntactic characteristics in terms of meaning, structure, and visual presentation.
- Mapping the impact on information quality by defining the relationships between label characteristics and information quality criteria.

Following a theoretical introduction to information labelling and information quality, the classification and definitions of informational labels on websites are presented. Subsequent sections provide a detailed analysis of four types of labels: contextual links, headings, navigation system elements, and index terms. Each analytical section includes a characterization of semantic and syntactic features along with the identification of their impact on information quality criteria. The article concludes with a summary and findings that outline theoretical and practical implications as well as future research directions.

2. Definition and Classification of Informational Labels on Websites

In academic literature, definitions and classifications of labelling are closely linked to information architecture models and content quality criteria. The labelling system in the information architecture of websites plays a pivotal role in ensuring usability and intuitiveness. Labelling refers to the process of assigning names or labels to resources, categories, sections, or functions within a website's informational system (Rosenfeld et al., 2017, pp. 119-120). Labels act as signposts that help users navigate the website and identify content. Their use enables effective information delivery while minimizing space consumption on webpages. In the context of information architecture, informational labels primarily take textual, graphical, or multimedia forms (Rosenfeld et al., 2017, pp. 124-134). Despite the increasingly visual nature of the internet, text labels remain dominant in classifying and organizing content on websites.

Rosenfeld et al. (2017, pp. 124-134) distinguish the following types of text labels: contextual links, headings, navigation system options, index terms. In the realm of web usability, J. Nielsen (2000, pp. 78-79) emphasizes their critical informational role in accelerating the evaluation of a webpage or its sections. These labels serve as linguistic representations of specific information fragments or functions, enabling users to orient themselves within the content structure and access desired data. Text labels thus fulfill a dual function: semantic (communicating content meaning) and syntactic (organizing content), making them indispensable components of information architecture. The subsequent sections of this publication analyze contextual links, headings, navigation system elements, and index terms across three domains:

- Public services (gov.pl).
- E-commerce (allegro.pl).
- Education (uni.opole.pl).

For each label type, semantic and syntactic characteristics are defined, along with their impact on selected information quality criteria.

3. Informational Labels as Contextual Links

Informational labels in the form of contextual links (hyperlinks) are characterized by a distinct structural specificity. Their purpose is to support navigation by directing users to related informational resources. These labels are not created within a systematic hierarchy but emerge ad hoc when the content author establishes a connection between the text and another informational element. Their semantic representation is strictly dependent on the context in which they are embedded. The meaning of embedded links is defined by the anchor text, i.e., the visible part of the hyperlink, which significantly impacts information quality in terms of usability. High semantic quality means the link accurately reflects the content of the resource it leads to. A well-constructed narrative context naturally guides users to destinations aligned with their expectations and informational needs.

The semantic properties of contextual links primarily concern their unambiguity, contextual relevance, accuracy, transparency, and credibility. The label's precision must unambiguously indicate the target content. For example: on gov.pl, a link titled "Check your PESEL number" (pl. „Sprawdź swój numer PESEL") clearly signals a verification function. Another link, "Apply for an ID card" (pl. „Złóż wniosek o dowód osobisty"), precisely communicates the redirection's purpose. A link embedded in text must integrate with the topic's context to enhance thematic relevance. For instance, a tax-related article should link to the PIT-37 form (gov.pl). In e-commerce, semantic alignment with user intent is critical. A link like "See similar products" (pl. „Zobacz podobne produkty"; allegro.pl) not only aids navigation but also adds value by contextually expanding choice options.

Labels that precisely describe the link's purpose avoid ambiguity. Generic terms like "Click here" (pl. „Kliknij tutaj") reduce transparency, whereas descriptive texts like "View class schedule" (pl. „Zobacz harmonogram zajęć") on university websites enhance clarity. Such semantics explicitly indicate user expectations (e.g., file downloads, form access). Similarly, "Check shipment status" (pl. „Sprawdź status przesyłki"; allegro.pl) unambiguously communicates the link's function. Clear, precise formulations minimize confusion, while vocabulary tailored to the audience's expertise improves comprehension in specialized contexts.

Beyond syntactic correctness and visual aesthetics, a key semantic feature is the credibility of the source. Links to authoritative sites (e.g., government portals, universities) increase user trust, unlike those directing to unsecured or disreputable pages. For example: links to public institutions (e.g., gov.pl) reinforce security and reliability. Reputable e-commerce platforms (e.g., allegro.pl) align with user expectations for transactional integrity. Thus, contextual links to credible sources enhance content perception and are vital for maintaining information quality.

Table 2.
Semantic Analysis of Contextual Links

Example Link (Website)	Semantic Analysis
"Apply for 800+" (pl. „Złóż wniosek o 800+", gov.pl)	Unambiguous link, indicates the function (application submission), relates to the context of family benefits.
"Check if you need to file a PIT" (pl. „Sprawdź, czy musisz rozliczyć PIT", gov.pl)	The link contains a question addressing real user needs – topical relevance.
"Check vehicle registration rules" (pl. „Sprawdź zasady rejestracji pojazdu", gov.pl)	Directs to an authoritative government source – ensures user trust in credible content.
"Buy and pay" (pl. „Kup i zapłać", allegro.pl)	Imperative form, clearly indicates the function – immediate purchase action.
"Delivery and payment" (pl. „Dostawa i płatność", allegro.pl)	Noun-based description of a thematic category – facilitates quick access to specific information.
"Check class schedule" (pl. „Sprawdź plan zajęć", uni.opole.pl)	Comprehensible link, relates to organizational functions – semantically aligned with student expectations.
"USOS System" (pl. „System USOS", uni.opole.pl)	Proper name of the system, understood by the target group – environmental semantic specificity.
"Offer for international candidates" (pl. „Oferta dla kandydatów zagranicznych", uni.opole.pl)	Precise identification of the target group and content type – semantic accuracy and personalization.
"Study regulations – download PDF" (pl. „Regulamin studiów – pobierz PDF", uni.opole.pl)	Official university website – high credibility.

Source: own elaboration.

Based on the examples of links presented in Table 2 and their semantic analysis, key characteristics of information quality can be identified: unambiguity, relevance, credibility, comprehensibility, personalization, and timeliness. Contextually well-embedded semantic links increase user satisfaction, reduce the time required to locate content, and support intuitive navigation within the website. Depending on the sector, link semantics may be more formalized (e.g., in public services), transactional (e-commerce), or informational-organizational (education).

The syntactic characteristics of contextual links relate to the grammatical and syntactic structure of the anchor text, as well as their visual presentation. From a linguistic perspective, an effective contextual link should be concise, legible, and grammatically correct. Rapid recognition of a link's meaning is enabled by short descriptions of 1-4 words (content conciseness). Verbal and nominal forms are preferred:

- Verbal structures (e.g., “Download” (pl. „Pobierz”), “Check” (pl. „Sprawdź”), “Sign up for training” (pl. „Zapisz się na szkolenie”)) provide clear calls to action.
- Nominal forms (e.g., “Registration form” (pl. „Formularz rejestracyjny”), “Terms of purchase” (pl. „Warunki zakupu”)) identify objects or informational categories.

Interrogative sentences (e.g., “How to obtain an ID card” (pl. „Jak uzyskać dowód osobisty”, gov.pl)) align with user mental models (e.g., student, taxpayer). In e-commerce, imperative forms like “Buy now” (pl. „Kup teraz”) or “Add to cart” (pl. „Dodaj do koszyka”) prompt immediate action. In education, phrases combining document or system names (e.g., “Registration form,” “USOS System”) reflect institutional communication styles.

The syntax of contextual links should also be considered in conjunction with visual hierarchy. Visual hierarchy refers to the way links are highlighted in the text (formatting) and their arrangement according to importance and function on the page. Elements of this hierarchy include text color, underlining, font size, placement within the text structure, and buttons as links. Using appropriate fonts and spacing, or distinguishing links with a different color, prevents the user from feeling overwhelmed and increases recognizability. Inserting a link directly into the content, in a place consistent with the narrative flow, is much more effective than placing it in the website footer. For example, after explaining a procedure on gov.pl, this shortens the navigation path. The traditional way to highlight an informational link is to underline the link text. Formatting links increases their accessibility—standard indicators include underlining and the color #0000EE. An example is the “Buy now” link (pl. *„Kup teraz”*, allegro.pl), distinguished from others by its orange color. Increasing the font size of a link determines its prominence in the user’s perception, as seen in “Add to cart” (pl. *„Dodaj do koszyka”*, allegro.pl). Placing links within textual structures—such as headings, paragraphs, bulleted lists, or numbered lists—enhances user attention. For instance, a link embedded in the “For Candidates**”** section (pl. *„Dla kandydatów”*, uni.opole.pl) improves discoverability. Another visual element is button-style links**,** exemplified by “Log in to ePUAP” (pl. *„Zaloguj się do ePUAP”*, gov.pl), which combine textual and graphical components to emphasize functionality.

The quality of contextual link labels can be enhanced by implementing three key elements: explanatory text**,** clear headings, and an unambiguous website purpose. A prime example of this practice is the contextual link labels on the gov.pl portal, which incorporate all the above elements. The website defines its target audience groups (e.g., *for citizens* (pl. *dla obywatela*), *for entrepreneurs* (pl. *dla przedsiębiorcy*), *for officials* (pl. *dla urzędnika*)) and uses intuitive headings such as *“Drivers and Vehicles”* (pl. *„Kierowcy i pojazdy”*) or *“Work and Business”* (pl. *„Praca i biznes”*). Additionally, heading labels include explanatory text, which provides a high degree of contextualization and ultimately enhances their semantic interpretability. Examples of links, along with an analysis of their syntax and visual hierarchy, are presented in Table 3.

Table 3.
Syntactic Analysis of Contextual Links

Example Link (Website)	Syntactic Form	Visual Hierarchy
"Report child's birth" (pl. „Zgłoś urodzenie dziecka", gov.pl)	Verb + noun	Underlined, blue, embedded in bulleted lists
"How to handle an official matter?" (pl. „Jak załatwić sprawę urzędową?", gov.pl)	Interrogative form	Smaller font, link within an informational text block
"Add to cart" (pl. „Dodaj do koszyka", allegro.pl)	Imperative form	Large button, orange color, central placement
"Buy and pay" (pl. „Kup i zapłać", allegro.pl)	Imperative form	Large button, orange color, central placement
"Registration form" (pl. „Formularz rejestracyjny", uni.opole.pl)	Noun phrase	Underlined, standard font, in sidebar
"Check class schedule" (pl. „Sprawdź plan zajęć", uni.opole.pl)	Imperative form	Highlighted button/darker text, featured on homepage

Source: own elaboration.

Based on the presented examples of links, their syntactic forms, and visual hierarchy, it is possible to identify key information quality characteristics such as comprehensibility, unambiguity, accessibility, transparency, functionality, usability, timeliness, and consistency. Clear, imperative, or task-oriented syntactic forms (e.g., "Report child's birth" (pl. „Zgłoś urodzenie dziecka"), "Add to cart" (pl. „Dodaj do koszyka"), "Buy and pay" (pl. „Kup i zapłać"), "Check class schedule" (pl. „Sprawdź plan zajęć")), combined with distinct visual emphasis (large button, contrasting color, central placement, underlining), significantly enhance the readability and accessibility of information, making it easier for the user to quickly understand and perform the intended action. The interrogative form ("How to handle an official matter?" (pl. „Jak załatwić sprawę urzędową?")) or the noun phrase ("Registration form" (pl. „Formularz rejestracyjny")), presented in a less visually prominent manner (smaller font, standard column), serve informational or navigational functions, supporting the completeness and consistency of information, though they do not always attract immediate attention. Visual hierarchy – through contrast, scale, color, and placement – assigns priority to the most important elements, guiding the user's gaze and organizing content by significance, which increases the transparency and functionality of the site. As a result, users can more easily find the information they need, and the overall message becomes more intuitive and user-friendly, which is crucial for high information quality on websites. The provided examples, which include the syntactic features of contextual links and visual hierarchy, function complementarily. A clear linguistic form enables the user to understand the meaning and function of the link, while appropriate visual emphasis attracts attention and highlights the importance of the information.

It should be emphasized that significant problems with the quality of contextual links include: excessive quantity on the page, lack of updates, and semantic inconsistency – all of which directly lower the level of the most important information quality characteristics on the site. An excess of links leads to information overload and a loss of transparency, making it difficult for users to quickly find key content. In turn, failing to verify the currency of links

results in users being redirected to incorrect or non-existent pages, which undermines timeliness and credibility. Links leading to a general page instead of using a precise URL (e.g., a "Download instructions" (pl. „Pobierz instrukcję") link) cause semantic inconsistency – reducing the unambiguity and consistency of the message. Proper design of the syntactic form of links and their visual hierarchy therefore not only improves the readability and functionality of the site but also minimizes the aforementioned quality issues, thereby supporting the comprehensibility, accessibility, timeliness, and consistency of information. Analysis of examples from public services, e-commerce, and education indicates that the effectiveness of contextual links is closely connected to their alignment with the user's mental model and the principles of user-centered design.

4. Informational Labels as Headings

Informational labels in the form of headings serve an important descriptive and structural function. Their primary purpose is to characterize the segment of information that follows them, enabling users to quickly identify the content of a given section. Moreover, headings reflect the hierarchy of content within a document, creating a multi-level organizational structure that facilitates navigation and understanding of relationships between individual informational elements. The structural function of labels used as headings relies heavily on visual elements such as text color, font size, numbering, indentation, or heading gradation. The aim of using these features is to distinguish heading labels from the main body text or to create a hierarchy among the headings themselves. For example, a heading label typically features a larger font size than the main text. Differentiating font sizes when using headings establishes a hierarchical organization of content. Thus, the use of informational labels as headings creates a multi-level categorization system, in which main (higher-level) headings define thematic areas, while subordinate headings specify detailed issues within a given area.

Table 4 presents the semantic and syntactic characteristics of headings on websites in three domains: public services (gov.pl), e-commerce (allegro.pl), and education (uni.opole.pl). The conducted analysis allows for the identification of both universal and domain-specific features of headings, as well as their potential impact on information quality.

Table 4.
Syntactic Analysis of Contextual Links

Domain (Website)	Semantic Characteristics	Syntactic Characteristics
Public Services (gov.pl)	- Precise reflection of the scope of services (e.g., "Documents and Personal Data" (pl. „Dokumenty i dane osobowe"), "Taxes" (pl. „Podatki")) - Use of language understandable to various citizen groups, e.g., for entrepreneurs, a phrase such as "Starting a Business" (pl. „Zakładanie firmy") - H1-H3 headings group thematic content into a logical whole, referencing user processes and tasks, e.g., the structure of the tax process	- Heading hierarchy H1-H3 (e.g., H1: "Taxes" (pl. „Podatki"), H2: "Annual Settlement" (pl. „Rozliczenie roczne"), H3: "PIT-37 Form" (pl. „Formularz PIT-37")) - Distinct formatting: font size, bold, color, numbering. Gradual decrease in font size from H1 to H6 (e.g., H1: 24 pixels, H2: 20 pixels) - Uniform structure of sections and subsections across the entire website
E-commerce (allegro.pl)	- Clear product categories (e.g., "Home and Garden" (pl. „Dom i ogród"), "Health" (pl. „Zdrowie"), "Automotive" (pl. „Motoryzacja")) - Contextual content, dynamically adjusted to trends and seasonality, e.g., "Weekly Promotions" (pl. „Promocje tygodnia") - Use of commercial terminology understandable to users, e.g., "Buy Now" (pl. „Kup teraz")	- Hierarchy H1-H3 (e.g., H1: "Electronics" (pl. „Elektronika"), H2: "Computers" (pl. „Komputery"), H3: "Computer Components" (pl. „Podzespoły komputerowe")) - Category headings highlighted in color #0066CC and 20-pixel font - Stylistic consistency within each category
Education (uni.opole.pl)	- Unambiguous definition of academic processes (e.g., "Session Schedule" (pl. „Harmonogram sesji"), "Academic Staff" (pl. „Pracownicy naukowi")) - Content adapted to the target group (e.g., candidate, student, staff) - Timeliness of content related to a given cycle, e.g., "Admissions 2025" (pl. „Rekrutacja 2025") - Linguistic relevance facilitating interpretation, e.g., "Assessment Rules" (pl. „Zasady zaliczeń")	- Hierarchy H1-H3 (e.g., H1: "Computer Science Major" (pl. „Kierunek Informatyka"), H2: "Study Program" (pl. „Program studiów"), H3: "Summer Semester 2025" (pl. „Semestr letni 2025")) - Bold, icons, contrast compliant with WCAG - Consistent style in logically grouped thematic sections

Source: own elaboration.

The presented examples of headings used on websites in the three domains illustrate their diversity both semantically and structurally.

The semantic characteristics of headings – such as precision of meaning, contextualization, and linguistic relevance – determine the clarity of communication and the alignment of content with user expectations and needs. The semantics of headings relate to the meaning and communicative function of the text, which serves as a label. For example, unambiguity, visible in headings such as "Taxes" (pl. „Podatki", gov.pl) or "Session Schedule" (pl. „Harmonogram sesji", uni.opole.pl), eliminates ambiguous interpretations by precisely defining the content scope and reducing the risk of misunderstanding. Contextualization, which involves integration between headings and content, reflects relationships between elements; for instance, "Weekly Promotions" (pl. „Promocje tygodnia", allegro.pl) adapts language to a specific audience or situation, increasing the accessibility and intuitiveness of the message. The use of terms tailored to the target group strengthens linguistic relevance, as in phrases like "Buy Now" (pl. „Kup

teraz", allegro.pl) or "Admissions 2025" (pl. „Rekrutacja 2025", uni.opole.pl), ensuring the timeliness and practical use fulness of information, which in turn enhances the credibility and usability of the content.

Structural characteristics include the hierarchy of headings, visual formatting, and stylistic consistency. These elements provide logical organization of content, recognizability, and support navigation. A structure based on HTML tags (e.g., H1: main categories, H2: subcategories, H3: sub-subcategories) demonstrates the logic of content organization, reducing the time required to find information by creating a structural hierarchy. Visual formatting, such as varying font sizes, text color, and spacing between headings, ensures the clarity of the navigation path. Consistently applying a uniform page layout, for example by using standardized section numbering such as "1. Documents" (pl. „Dokumenty"), "1.1. Identity Card" (pl. „Dowód osobisty"), allows users to quickly access specific information or services.

Headings, as informational labels, have a multidimensional impact on specific information quality characteristics on websites:

- Accessibility: A hierarchical and logical structure of headings facilitates the quick discovery and understanding of information, which is crucial for effective user navigation.
- Consistency: Uniform terminology and style in headings build predictability, increase trust in the website, and make it easier to orient oneself within the content.
- Comprehensibility: Precise and relevant headings group content into logical blocks, enhancing the clarity of communication and minimizing the risk of user confusion.
- Completeness: Headings organize content into complete, self-contained thematic sections, making it easier for users to gain a comprehensive understanding.
- Timeliness: Dynamic headings reflect changes in content, enabling rapid adaptation of the presented information to current needs.

5. Informational Labels in Navigation Systems

Navigation labels are intended to indicate the direction of navigation for the user within a website, enabling quick access to specific resources and allowing users to move between pages or sections of the site (Garrett, 2010, pp. 65-66). Typical examples of their use include the main menu, navigation bars, and buttons. These elements perform key tasks derived from the principles of information architecture and information quality management. The main menu is responsible for the logical segmentation of content and users, providing rapid access to the most important areas of the site and tailoring the navigation path to the recipient's needs. A well-designed menu increases the relevance, accessibility, and clarity of information,

reducing search time and minimizing the risk of user confusion. Navigation bars (breadcrumbs) display the user's current location within the site structure and make it possible to quickly return to higher levels of the hierarchy. As a result, they improve orientation within the site, shorten the path to information, and support clarity and predictability in navigation. Buttons, in turn, serve task-oriented functions by initiating specific user actions (e.g., starting a process, submitting a form, proceeding to the next step). They are often based on graphic elements or icons that, instead of text, represent functions or page content. These operate similarly to text, though with certain limitations and specific applications. Icons constitute an alternative form of information representation in navigation systems, especially in mobile applications where screen space is limited.

The navigation system of a website typically contains a limited number of options, which means that these labels must be used with particular consistency. The importance of consistency in navigation systems is emphasized by Rosenfeld et al. (Rosenfeld et al., 2017, pp. 130-132). This feature builds a sense of security and confidence when navigating the site, as the user becomes familiar with its structure. Inconsistent navigation options are highly noticeable and result in a negative evaluation from the user. Using different labels to define the same function in various sections of the site is an example of poor practice. Users base their interactions with the system on the assumption of rationality and predictability of navigation elements throughout the entire website, and such inconsistency negatively affects the semantic and functional consistency of navigation labels. Problems with navigation label naming, such as word ambiguity (polysemy) – for example, "Services" – or excessive specialization due to technical terms incomprehensible to laypersons, require the use of additional explanatory elements. The implementation of contextual hints, activated by hovering the cursor over a label, allows for the display of additional information explaining the semantic scope of a given navigation element. This technique makes it possible to keep labels concise while ensuring the precision of their interpretation. A good practice example is the navigation system of the gov.pl portal, which provides a comprehensive example of the use of textual labels to organize access to public services. These labels are characterized by a high degree of standardization and semantic consistency, which is crucial for providing a predictable user experience. Informational labels in the main categories of the navigation system are highly abstract, yet they unambiguously communicate the thematic scope of the information they contain, such as "Education" (pl. „Edukacja"), "Work and Business" (pl. „Praca i biznes"), or "Travel" (pl. „Podróże"). Labels in navigation subsystems contain more detailed names that specify particular administrative services. Examples of labels in the "Agriculture" (pl. „Rolnictwo") category include: "Direct Payment" (pl. „Płatność bezpośrednia"), "Assessment of Crop Losses" (pl. „Oszacowanie strat w uprawach rolnych"), "Excise Tax on Agricultural Fuel" (pl. „Podatek akcyzowy za paliwo rolnicze"), and "Phytosanitary Certificate" (pl. „Świadectwo fitosanitarne").

In practice, the naming of informational labels may vary depending on the industry or their area of application within navigation systems. Among the most popular informational labels in the navigation systems of e-commerce websites are: *Bestsellers* (pl. „Bestsellery"), *New Arrivals* (pl. „Nowości"), and *Promotions* (pl. „Promocje"). On the websites of higher education institutions in Poland, frequently used labels include: *About the University* (pl. „O uczelni"), *Students* (pl. „Studenci"), *For Candidates* (pl. „Dla kandydatów"), and *Science and Research* (pl. „Nauka i badania"). Nevertheless, informational labels (navigation system labels) on many websites feature popular names familiar to most internet users. These include labels such as: *Home Page* (pl. „Strona główna"), *News* (pl. „Aktualności"), *About Us* (pl. „O nas"), *Find* (pl. „Znajdź"), *Contact* (pl. „Kontakt"), and *Help* (pl. „Pomoc"). Table 5 provides examples of informational labels in navigation systems (main menu, buttons, navigation bars) for three areas: public services, e-commerce, and education.

Table 5.
Examples of informational labels in navigation systems: main menu, buttons, navigation bars

Element Type	Public Services (gov.pl)	E-commerce (allegro.pl)	Education (uni.opole.pl)
Main Menu	- *Services for Citizens* (pl. „Usługi dla obywatela") - *Services for Entrepreneurs* (pl. „Usługi dla przedsiębiorcy") - *Services for Officials* (pl. „Usługi dla urzędnika") - *Services for Farmers* (pl. „Usługi dla rolnika") - *Chancellery of the Prime Minister* (pl. „Kancelaria Premiera") - *Council of Ministers* (pl. „Rada Ministrów") - *Ministries* (pl. „Ministerstwa")	- *Categories* (pl. „Kategorie") - *My Allegro* (pl. „Moje Allegro") - *Smart!* (pl. „Smart!") - *Home and Garden* (pl. „Dom i ogród") - *Fashion* (pl. „Moda") - *Weekly Promotions* (pl. „Promocje tygodnia") - *Bestsellers* (pl. „Bestsellery")	- *University* (pl. „Uczelnia") - *For Student* (pl. „Dla studenta") - *For Employee* (pl. „Dla pracownika") - *Admissions* (pl. „Rekrutacja") - *Science* (pl. „Nauka") - *Cooperation* (pl. „Współpraca") - *HRS4R* (pl. „HRS4R")
Buttons	- *Log in to ePUAP* (pl. „Zaloguj się do ePUAP") - *Log out* (pl. „Wyloguj") - *Check Application Status* (pl. „Sprawdź status wniosku") - *Submit Application Online* (pl. „Złóż wniosek online")	- *Buy Now* (pl. „Kup teraz") - *Add to Cart* (pl. „Dodaj do koszyka") - *Watched* (pl. „Obserwowane") - *Cart* (pl. „Koszyk")	- *Sign Up* (pl. „Zapisz się") - *See Schedule* (pl. „Zobacz harmonogram") - *Download Syllabus* (pl. „Pobierz sylabus") - *Book an Appointment* (pl. „Zarezerwuj termin")
Navigation Bar	- *Services for Citizens > Documents and Personal Data > Identity Card* (pl. „Usługi dla obywatela"> „Dokumenty i dane osobowe" > „Dowód osobisty") - *Services for Entrepreneurs > Starting a Business > I Want to Set Up a Joint Stock Company* (pl. „Usługi dla przedsiębiorcy" > „Zakładanie firmy" > „Chcę założyć spółkę akcyjną")	- *Electronics > Phones and Accessories > GSM Accessories* (pl. „Elektronika" > „Telefony i akcesoria" > „Akcesoria GSM") - *Child > Toys > Blocks > Lego* (pl. „Dziecko" > „Zabawki" > „Klocki" > „Lego")	- *For Student > Usos* (pl. „Dla studenta" > „Usos") - *Admissions > Studies 2025/2026 > Admission Dates* (pl. „Rekrutacja" > „Studia 2025/2026" > „Terminy rekrutacji")

Source: own elaboration.

Based on the analysis of informational labels in navigation systems (menus, bars, buttons), a set of semantic and syntactic characteristics was identified. The general semantic characteristics of informational labels in navigation systems on websites include:

- Unambiguity: the label presents clear and understandable categories (e.g., "Taxes" (pl. „Podatki"), "Electronics" (pl. „Elektronika"), "For Candidate" (pl. „Dla kandydata")).
- Relevance – alignment with user needs and task context (e.g., "Admissions 2025" (pl. „Rekrutacja 2025")).
- Contextualization: placing the label in the appropriate area of the site's structure; considering the place and situation of use.
- Semantic consistency: consistent use of terminology throughout the entire navigation system (e.g., stylistic consistency).
- Functional transparency: clearly indicating the outcome of an action (e.g., "Log out – you will lose access to services" (pl. „Wyloguj – utracisz dostęp do usług")).
- Personalization/segmentation: tailoring labels to the user's profile or segment (e.g., "My Cases" (pl. „Moje sprawy"), "For Entrepreneur" (pl. „Dla przedsiębiorcy")).
- Directness of communication: clearly specifying the result of clicking or selecting (e.g., "Add to cart" (pl. „Dodaj do koszyka"), "Sign up" (pl. „Zapisz się")).
- Timeliness: signaling new, changed, or time-limited functions (e.g., "New" (pl. „Nowość"), "Weekly Promotions" (pl. „Promocje tygodnia")).

Among the syntactic characteristics of labels in navigation systems, the following can be distinguished:

- Hierarchy: logical ordering of labels (e.g., main menu > submenu > options), supporting user orientation.
- Formatting: highlighting (e.g., font, color, bold, icon) that facilitates quick recognition and scanning.
- Layout and number of options: limiting the number and length of visible labels, logical grouping to facilitate quick decision-making by the user.
- Responsiveness: adapting the layout and label visibility to different devices (e.g., smartphone, laptop) and screen resolutions.
- Visual hierarchy: differentiating label importance through size, color, placement, presence of icons or buttons.
- Integration with other mechanisms: linking labels with search, navigation bars, filters, notification systems.
- Dynamic state: labels/buttons changing depending on context, status, or user action (e.g., "Added to cart" (pl. „Dodano do koszyka")).
- Digital accessibility: compliance with WCAG, readability for screen readers, appropriate contrast and size.

Some of the presented semantic and syntactic characteristics of informational labels in navigation systems go beyond the classic aspects of headings and contextual links discussed in this publication. They are crucial for building modern, effective, and inclusive interfaces. These features not only allow for better adaptation to user needs and context but also ensure high information quality. Characteristics such as personalization, functional transparency, and segmentation of the offering enhance the level of user experience individualization, increase credibility and predictability of interactions, and support verifiability and information security. Meanwhile, multichannel integration, adaptability, responsiveness, dynamic state, and digital accessibility increase the usability of the navigation system, ensure access for different user groups (including people with disabilities), and enable effective information management in a multiplatform environment. Dynamic changes in labels (e.g., "Added to cart" (pl. „Dodano do koszyka")) increase interactivity and operational efficiency, while contextual layout and minimalism in the number of options reduce cognitive overload and improve navigation clarity.

All three navigation system elements – through appropriately designed labels – significantly enhance the quality of information on the website, impacting its accessibility, relevance, comprehensibility, and usability for the user. A main menu based on audience segmentation, such as: "Services for Citizens" (pl. „Usługi dla obywatela"), "Services for Entrepreneurs" (pl. „Usługi dla przedsiębiorcy") (gov.pl), increases the relevance and accessibility of information by quickly tailoring the navigation path to user needs. Buttons support navigation efficiency and minimize the risk of errors (e.g., "Submit Application Online" (pl. „Złóż wniosek online"), "Buy Now" (pl. „Kup teraz"), "Sign Up" (pl. „Zapisz się")). Navigation bars reflect process logic in public administration services (gov.pl), filtering on e-commerce platforms (allegro.pl), or the academic cycle on university websites (uni.opole.pl), thereby improving site orientation and shortening the path to information. Contextual links are embedded in appropriate sections and precisely describe their function, increasing the relevance and comprehensibility of the message.

6. Informational Labels as Index Terms

Index terms used in the indexing process are a key element of information architecture, enabling the integration of information on websites. Index terms such as keywords, tags, phrases, or controlled vocabularies and thesauri describe the subject matter of content (content organization function for the user), enable precise searching (content filtering), and support content classification processes on websites. For example, tags are often used to group content by topic, which supports the indexing process by search engines (tag hierarchy). According to Rosenfeld et al (2017, pp. 132-134), index terms improve browsing of site content, subpages,

and content fragments, creating an alternative to the basic content organization system. By presenting the meaning of a content fragment as an index term, more precise searching is possible compared to full-text search. Index terms are linked to search engines and filters, allowing users to quickly and accurately find the needed content without having to browse the entire site. For example, an advanced public service search engine (gov.pl) enables filtering by category; on an auction portal, products can be filtered by tags, manufacturers, or features (allegro.pl); and on a university website (uni.opole.pl), the scientific publication search engine uses a keyword index. Informational labels represented by index terms are also crucial for indexing pages by search engines. Properly selected metadata increase the likelihood of a website being found by users using search engines. Content organization through indexing enables grouping and classification of content according to specific criteria, such as subject, time, or location. M.J. Eppler points out that hierarchical indexing structures allow for efficient management of large data sets by logically organizing them (2006, p. 65). Integration of information by linking dispersed data into coherent structures, creating connections between elements (e.g., through metadata), allows users to interpret data more easily in relation to their application (Eppler, 2006, p. 146). Thus, indexing is a mechanism for contextualizing information, assigning meaning by embedding it in a network of relationships. Indexing also optimizes the content search process through the use of, for example, tags or keywords, enabling precise information filtering. M.J. Eppler emphasizes the importance of automatic indexing in content management systems, which increases search efficiency and reduces the time needed to find information (2006, p. 183).

Index terms often interact with one of the three basic types of text labels in information architecture on websites – contextual links (pl. linki kontekstowe), headings (pl. nagłówki), and navigation labels (pl. etykiety nawigacyjne). In practice, the boundaries between these types of labels are fluid and frequently overlap, serving complementary functions within the information organization system. Index terms may appear as anchor text in contextual links, guiding users to thematically related resources and thereby simultaneously facilitating navigation and increasing the relevance and accessibility of information (e.g., “PIT-37 Form” (pl. „Formularz PIT-37”) as a link in the tax section). They may also serve as headings for sections or subpages, acting as thematic descriptors that organize content into logical blocks and establish hierarchy, which makes browsing and searching for information easier – for example, “Taxes” (pl. „Podatki”) as both a heading and an index term in the public services catalog (gov.pl). Additionally, in navigation systems, index terms are used as labels for navigation options such as categories, tags, or thematic sections (“Education” (pl. „Edukacja”), “Health” (pl. „Zdrowie”), “Electronics” (pl. „Elektronika”)), which enables quick filtering and classification of content and makes them an integral part of the navigation interface. Such overlapping of roles allows for consistent and multidimensional indexing of content, minimizing search time and increasing user satisfaction. On the other hand, excessive overlap of these functions without maintaining semantic and syntactic consistency can lead to user

confusion, duplication of information, or navigational inconsistency. Therefore, it is crucial to consistently apply labelling principles, hierarchy, and unambiguous naming.

Index terms, contextual links, headings, and navigation system elements share a set of common structural and semantic features, as discussed in the descriptions of each informational label. The key shared structural features include, above all, content hierarchy, stylistic consistency, and integration with the information architecture – labels are an integral part of organization, labelling, and navigation systems. In terms of semantic features, all text labels share unambiguity and precision, relevance, and contextualization resulting from their placement within the site structure.

Against this background of shared features, index terms stand out with specific structural and semantic characteristics that distinguish them from other types of labels on websites. Among the specific structural features of index terms is, above all, thematic indexing, which involves creating logical, often hierarchical structures of connections, such as tag lists or topic directories. An example of this feature is the structure on the government portal (gov.pl), where the term "Services for Citizens" (pl. „Usługi dla obywatela") leads to further subcategories, such as "Documents and Personal Data" (pl. „Dokumenty i dane osobowe"), and then to more detailed topics, e.g., "Identity Card" (pl. „Dowód osobisty"), which enables quick access to the relevant category regardless of one's location in the site structure. Another important feature is cross-referencing – index terms enable the linking of related content and the building of a network of connections, allowing users to smoothly transition between different but thematically related resources. For example, the tag "Taxes" (pl. „Podatki") connects articles on various tax aspects. Another example is the tag "GSM Accessories" (pl. „Akcesoria GSM", allegro.pl), which is linked both to the "Electronics" (pl. „Elektronika") category and to products such as "Chargers" (pl. „Ładowarki") or "Cases" (pl. „Etui"), enabling users to move fluidly between different but related resources. Modularity and scalability are also important – the index term system can be easily expanded with new concepts without the need to reorganize the entire structure. This is especially important for dynamically developing websites. For example, on a university website (uni.opole.pl), it is easy to add new terms such as "Online Courses" (pl. „Kursy online") or "Psychological Support" (pl. „Wsparcie psychologiczne") to the existing structure, while maintaining consistency and clarity.

On the semantic level, index terms are distinguished by precise terminology based on specialized and unambiguous concepts, often in accordance with controlled industry or institutional vocabularies, e.g., official names such as "PIT-37 Form" (pl. „Formularz PIT-37") or "Identity Card" (pl. „Dowód osobisty", gov.pl). This eliminates ambiguity and polysemy, resulting in higher information quality. Multidimensional categorization allows a single term to be assigned to multiple contexts or categories, increasing the flexibility of the content organization system; for example, the term "Scholarships" (pl. „Stypendia") appears in both the "For Students" (pl. „Dla studentów"), "For Doctoral Students" (pl. „Dla doktorantów"), and "Financial Support" (pl. „Wsparcie finansowe") sections. Additionally, index terms serve

as metadata for describing and classifying content, supporting advanced search and filtering according to various criteria. Examples include tags such as "Smartphones" (pl. „Smartfony"), "New Arrivals" (pl. „Nowości"), or "Weekly Promotions" (pl. „Promocje tygodnia", allegro.pl), which enable quick filtering and product discovery, increasing the relevance of search results.

The impact of these features on information quality is multidimensional. Above all, they increase accessibility and search speed, as logical indexing and cross-references shorten the time needed to access required data. Narrowing search results to the most relevant resources reduces search time and increases user satisfaction. As a result, information becomes more accessible and relevant, and users can make decisions more quickly based on current and complete data. Precise terminology and multidimensional categorization improve consistency and unambiguity, eliminating the risk of misinterpretation. The metadata function enhances the relevance and usefulness of information, enabling personalized results and efficient filtering even in very extensive websites. The modularity and scalability of the index term system allow for dynamic content development without losing the clarity and consistency of the information structure. Ultimately, the specific features of index terms translate into higher information quality, supporting both users in quickly and accurately finding content and administrators in efficiently managing information resources.

7. Conclusions

Informational labels constitute a key element of information architecture, and their proper implementation ensures appropriate information quality. The characterization of four categories of labels presented in this publication has made it possible to demonstrate their impact on a range of information quality characteristics. The analysis was conducted based on a study of informational labels on websites in three key areas: public services (gov.pl), e-commerce (allegro.pl), and education (uni.opole.pl). These diverse areas allow for a comprehensive approach to the issue of labelling, taking into account the specifics of each sector.

Table 6 presents the semantic and syntactic characteristics as well as their possible impact on information quality in the online environment.

Table 6.
Overview of the semantic and syntactic characteristics of informational labels and their impact on information quality

Label Type	Semantic Characteristic	Syntactic Characteristic	Information Quality Characteristic (Impact on Information Quality)
Contextual Links	Name precision (unambiguous indication of content)	Content conciseness (1-4 words) using verbs or nouns	Unambiguity (elimination of ambiguous content interpretations)
	Contextual fit to content	Placement in text consistent with narrative (e.g., embedded in a paragraph)	Relevance (increasing the accuracy of information relative to user needs)
	Clear statement of link purpose	Contain hyperlinks within page content	Accessibility (faster finding of needed information)
	Links to authoritative sources – credible sources	SSL certificate	Credibility (building trust in the presented content)
	Dynamic labels adapted to current trends	Responsiveness (adaptation to mobile devices)	Timeliness (ensuring consistency with reality)
	Personalization (adaptation to the recipient)	Grammatical correctness	Comprehensibility (facilitating content interpretation)
	Thematic relevance	Visual hierarchy (highlighting, color, position)	Usability (readiness for use – effective searching and use of content)
Headings	Unambiguous definition of headings	Structural hierarchy of headings (H1-H6) and color contrast	Accessibility (easier finding and understanding of information)
	Uniform naming of headings throughout the site	Fixed arrangement of headings in various sections, numbering (logical segmentation)	Consistency (uniform structure)
	Linguistic relevance (terminology adapted to the target group), content contextualization	Stylistic formatting consistency (size, font, color, indentation)	Comprehensibility (clarity of message, minimizing confusion)
	Communication of the full content scope, precise reflection of content range	Logical division of content into closed sections, integration with navigation system	Completeness (full information)
	Dynamic headings (updating presented information)	Formatting changes (color/font) to highlight new items, responsive design (e.g., adaptation to mobile devices)	Timeliness (reflecting content changes)
Navigation System Labels	Unambiguity (clear categories)	Menu hierarchy (e.g., main categories > subcategories), dynamic adaptation of labels to context	Accessibility (quick access to key site areas)
	Relevance (adaptation to user needs)	Formatting (visual highlighting)	Transparency (facilitating site orientation)
	Contextualization (placement within structure)	Layout and number of options (limiting quantity)	Predictability (consistent structure)
	Semantic consistency (consistent terminology)	Responsiveness (adaptation of label layout to devices)	Usability (navigation efficiency)
	Functional transparency (clear indication of action outcome)	Visual hierarchy (prioritization)	Relevance (path adaptation to needs)
	Personalization/segmentation (adaptation to user profile)	Integration with other mechanisms (e.g., filters, search engines, breadcrumbs)	Verifiability (certainty of function)

Cont. table 6.

	Timeliness (signaling changes)	Dynamic state (labels changing depending on context)	Timeliness (ensuring consistency with reality)
	Terminological consistency (stylistic consistency)	Fixed menu layout	Consistency (uniform structure)
Index Terms	Terminology standardization (semantic consistency)	Structural consistency	Consistency (uniform layout on all subpages)
	Precise terminology (unambiguous concepts)	Modularity and scalability (ease of expansion)	Accessibility (shortening time to information)
	Unambiguous terminology	Thematic indexing (logical structures)	Unambiguity (precise content indication)
	Multidimensional categorization (flexible classification)	Cross-references (network of connections)	Relevance (personalization of search results)
	Thematic connections	Hierarchical structures	Completeness (full access to information)
	Metadata function (search support)	Integration with search and filters	Search and filtering speed

Source: own elaboration.

Table 6 reveals significant relationships between the semantic and syntactic properties of informational labels and the quality outcomes they generate in the context of websites. It should be emphasized that this is not a closed set of features and their effects. Various configurations of the characteristics identified in the study and their impact on information quality are possible.

The conducted study revealed differences in label characteristics between the public services, e-commerce, and education sectors, reflecting the specific needs of users and the operational context of each website. The analysis of informational labels allowed for the identification of semantic and syntactic characteristics influencing seven primary information quality criteria. The most frequently occurring semantic characteristics were unambiguity, relevance, and contextualization, while personalization and segmentation were the least represented. Dominant syntactic characteristics included visual hierarchy, formatting, and stylistic consistency, whereas responsiveness and integration with search mechanisms were observed less frequently.

Seven dominant attributes determining information quality were identified: accessibility, consistency, timeliness, relevance, completeness, unambiguity, and usability. These attributes occur with the highest frequency across the structure of different label types. Semantic characteristics, which focus on the meaning and communicative function of labels, directly translate into quality aspects such as unambiguity, relevance, and message credibility. On the other hand, syntactic characteristics, encompassing the structural organization and presentation of labels, primarily influence accessibility, clarity, and the efficiency of information retrieval.

The interaction between semantic and syntactic characteristics is also critical. The highest information quality is achieved through the synergistic combination of precise semantics with an appropriate presentation structure. Regardless of the label type, its embedding in the appropriate context – both semantic and structural – is a key condition for high information

quality. Contextualization enhances the relevance, comprehensibility, and usability of the conveyed content.

The introduced analytical approach, combining semantic and syntactic perspectives in information quality research, contributes to the theory of information architecture and information quality management. The identified information quality characteristics of informational labels show significant alignment with universal information quality models (Kahn, Strong, Wang; English; Eppler; Stvilia et al.). Common characteristics include unambiguity (clarity), relevance, accessibility, consistency, and timeliness. The obtained results confirm their applicability in designing information quality-oriented user interfaces. Effective labelling of information on websites requires a balanced approach to semantic and syntactic characteristics. Practical implications also include the need for systematic auditing and optimization of labelling systems as part of a holistic information quality management strategy for websites. Continued research will enable the development of labelling standards for different types of online services.

Proper label design requires an understanding of both semantic (meaning, terminology) and syntactic (structure, formatting) aspects. Based on the conducted study, practical recommendations for website designers can be proposed in these two areas:

1. Designing semantic labels:
   - Use unambiguous terminology tailored to the target audience.
   - Ensure contextualization of labels in relation to surrounding content.
   - Implement mechanisms to verify label relevance.
2. Optimizing syntactic characteristics:
   - Apply visual hierarchy consistently across the entire system.
   - Ensure label responsiveness across devices.
   - Integrate labels with navigation and search systems.

A limitation of the conducted study is the analysis based on individual Polish-language websites from three sectors (public services, e-commerce, education), which may not reflect the full diversity of labelling practices within the industry. The cross-sectional nature of the study prevents observation of changes in labelling practices or their long-term impact on information quality. Cultural and linguistic differences pose significant limitations that may influence label interpretation and user experience:

- Cultural mental models of users affect how informational labels are interpreted (e.g., cultural context of international websites).
- Linguistic contexts characterized by distinct grammatical structures and communication conventions.
- Regulatory frameworks for digital accessibility and information standards, which may vary significantly between countries.

Future studies should expand the analysis to additional industries and service types (e.g., healthcare, finance, media) and incorporate dynamic aspects of labels (e.g., algorithmically generated labels, personalization).

References

1. English, L. (1999). *Improving Data Warehouse and Business Information Quality: Methods for Reducing Costs and Increasing Profits*. New York: John Wiley & Sons Inc.
2. Eppler, M.J. (2006). *Managing Information Quality: Increasing the Value of Information in Knowledge-intensive Products and Processes*. Berlin/Heidelberg/New York: Springer.
3. Floridi, L. (1999). Information ethics: On the philosophical foundation of computer ethics. *Ethics and Information Technology*, *Vol. 1*, pp. 33-521.
4. Garrett, J.J. (2010). *The Elements of User Experience: User-Centered Design for the Web and Beyond*. 2nd Edition. Berkeley, CA: New Riders.
5. Ghalavand, H., Nabiolahi, A. (2024). Exploring online health information quality criteria on social media: a mixed method approach. *BMC Health Services Research*, *Vol. 24*, pp. 1-15.
6. Gupta, U. (2000). *Information Systems: Success in the 21st Century*. New Jersey: Prentice Hall.
7. Horn, R.E. (1989). *Mapping Hypertext - Analysis, Linkage, and Display of Knowledge for the Next Generation of On-Line Text and Graphics.* Waltham: The Lexington Institute.
8. Kahn, B.K., Strong, D.M., Wang, R.Y. (2002). Information Quality Benchmarks: Product and Service Performance. *Communications of the ACM*, *Vol. 45, No. 4,* pp. 184-192.
9. Krzesaj, M. (2022). Tools of Improving the Quality of Information On Websites. *Scientific Papers of Silesian University of Technology Organization and Management Series*, *No. 163,* pp. 323-341.
10. Krzesaj, M. (2024). The Impact of Information Organisation Schemes on the Quality of Information on the World Wide Web. *Scientific Papers of Silesian University of Technology Organization and Management Series*, *No. 197,* pp. 425-442.
11. Nielsen, J. (2000). *Designing Web Usability: The Practice of Simplicity*. New Riders.
12. NIST (2022). *Recommended Criteria for Cybersecurity Labelling of Consumer Software.* NIST Cybersecurity White Paper CSWP.02042022-1. https://doi.org/10.6028/NIST.CSWP.02042022-1.
13. Rosenfeld, L., Morville, P., Arango, J. (2017). *Architektura informacji w serwisach internetowych i nie tylko*. Gliwice: Helion.
14. Stvilia, B., Les Gasser, M.B., Twidale, Smith, L.C. (2007). A Framework for Information Quality Assessment. *Journal of the American Society for Information Science and Technology*, *Vol. 58, No. 12*, pp. 1720-1733.

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SELECTED METHODS FOR MEASURING MARKET AND SECTOR GLOBALIZATION AND ENTERPRISE INTERNATIONALIZATION

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Purpose: This paper aims to identify and describe the methods for measuring the level of globalization of national economies and sectors, as well as the level of internationalization of the business activities of manufacturing enterprises.
Design/methodology/approach: The paper is of a theoretical nature. The literature review served as the starting point, allowing for the assessment of the current state of knowledge on measuring globalization and internationalization. This allowed for the formulation of the research problem.
Findings: There is no single, universally recognized and accepted way to measure globalization, either at the level of economies or sectors. Globalization is a complex, complicated and multidimensional process. Researchers propose qualitative approaches, while quantitative measurement concepts are also known and developed. The level of internationalization is most often studied through the prism of either geographical scope or the degree of foreign involvement in particular activities.
Research limitations and implications: The research systematizes and synthesizes scientific knowledge in measuring the processes of globalization and internationalization. The main limitation of this research is that, due to the complexity of the studied phenomena and the nature of this article, it is not possible to provide a comprehensive analysis or exhaustive description. The paper presents only the most useful attempts to formally describe these, after all, qualitative economic phenomena.
Practical and social implications: The article is addressed mainly to the scientific community. The methods presented here can be a starting point for discovering new relationships and interdependencies. For example, the relationship between the level of internationalization and corporate performance can be studied. The results of such research can help managers make decisions about the scope and intensity of a company's foreign operations.
Originality and value: The originality of the research lies in the attempt to systematize and synthesize the scattered scientific studies on measuring the internationalization of enterprises and the globalization of sectors and economies. The conclusions of this paper contribute to a better understanding of these phenomena.
Keywords: internationalization, strategy, management, measurement.
Category of the paper: research paper.

1. Introduction

An enterprise seeks different opportunities to grow. Among the most important decisions is whether to choose a strategy of specialization or diversification (Kaulich, 2012). Another crucial choice is the one of the scale of operations. A small scale of operations translates into greater organizational flexibility, manifested in the ability to respond quickly to changes in the environment. On the other hand, such enterprises are less resistant to the confrontational competitive moves of larger and stronger rivals who have significantly more resources that provide greater opportunities for various development activities. Another issue is to decide whether to operate regionally, nationally or globally (Verbeke, Asmussen, 2016). Choosing how to compete requires adopting the right approach to serve markets. Choosing a large scale of operations often involves competing on cost or differentiation (Baker et al., 2016).

One way to grow a business is to adopt an internationalization strategy. Internationalization, in the simplest terms, means going beyond the borders of one's own country with the aim of increasing the enterprise's growth opportunities. This implies the need for the executives to adopt a global perspective and focus on foreign markets, which raises a number of strategic issues. Yip (1996) has shown that sectors and markets can have both global and local characteristics. Optimal exploitation of the potential of these markets is only possible if the overall strategy of the company is designed, implemented and consistently executed, including the assumptions of operating in foreign markets. This action must be coordinated on an enterprise-wide level, with resources properly configured. That means they should be adapted to suit the requirements of local markets while also providing added value from the perspective of the entire enterprise.

The result of an enterprise's foreign involvement is a shift of some resources to foreign markets. The degree of this shift constitutes an interesting research problem. The fundamental question in this area is how to study the extent and intensity of an enterprise's foreign operations. This work attempts to answer this question.

2. Research methodology

The study employs a research approach based on a literature review. The research process consisted of the following steps:

- Literature review: A thorough review of monographs and scientific articles was conducted. Reputable databases, including Scopus, Web of Science, ScienceDirect, were used to gather relevant literature. The literature covered the issues of internationalization of business operations and globalization.

- Formulation of the research problem: The literature review enabled the identification of a research gap. No studies were identified that comprehensively describe measurement methods of both the enterprise and its immediate environment (sector) and further environment (national economy). This allowed for the formulation of the research objective. The purpose of this paper is to identify and describe methods of measuring the level of globalization of national economies and sectors, as well as the level of internationalization of the activities of manufacturing enterprises.
- Information collection: Data was obtained from scientific articles, monographs, market reports and studies by international institutions.
- Analysis of collected information: The gathered data underwent careful selection and rigorous analysis based on the research objective. The classical assumptions of the qualitative approach were applied.
- Results and recommendations: The article concludes with findings and recommendations for businesses and researchers.
- Limitations: This paper serves as a research report aimed at systematizing knowledge on measuring internationalization and globalization. The article, as a form of scientific expression, does not allow for a comprehensive and complete description due to its limited volume. Furthermore, this study does not provide a complete catalogue of measurement methods. Instead, only the most useful ones from the perspective of the future research have been presented. The selection focuses on methods that enable the comparative analysis of objects in a horizontal framework.

In order to achieve the purpose of the work, it is necessary to provide a broad theoretical context. This issue will be addressed in the subsequent chapter.

3. Theoretical overview

Mintzberg and Quinn (1996) argue that strategy should provide an answer to the question of how an enterprise should act to gain and maintain the desired competitive position in the market. Strategy is a category in management theory that has become the basis for distinguishing strategic management. One of the most important elements that distinguishes the classical management approach from strategic management is time perspective and long-term planning. This was taken into account in the studies by Ansoff (1965); Andrews (1987); Grant (1991). Long-term planning makes it possible to align an enterprise’s overall strategy with its environment (Stonehouse, Pemberton, 2002). In addition to the planning approach, McKiernan (1997) identified three other leading management approaches: evolutionary (learning), positioning and resource balancing. The evolutionary approach assumes that an organization's strategy will begin to emerge and develop spontaneously over time. Its proponents: (Quin,

1978; Mintzberg et al., 1995) argued that the organization will manage itself as a result of adapting to the changing environment. The positioning approach is associated primarily with Porter (1980). The main criticism of this approach emphasized its static nature, and that the profitability of a sector does not necessarily determine the profitability of an enterprise. Rumelt (1991) additionally emphasized the neglect of cooperation opportunities and a greater focus on the external environment rather than on an organization's competence. The resource balancing approach is different. It focuses on the relationship between an enterprise's resources and its competitive advantage (Prahalad, Hamel, 1990; Barney, 1991; Barney et al., 2001; Krupski, 2006). An enterprise is a collection of resources that distinguish it from others and shape its position (Obłój, 2007).

Strategic management is a response to the increasing level of uncertainty in the business environment of enterprises (Baker, Bloom, 2016). It seeks new methods of building competitive advantage, as classic management methods are insufficient (Binnis et al., 2014; Kaplan, Orlikowski, 2015). For effective management, an enterprise must increase its strategic flexibility, which involves of the ability to adapt to changes in the environment (Shimizu, Hit, 2004).

The most important schools of strategic management have been characterized above. Central to this is strategy. Strategy is an integrated and coordinated set of actions taken to utilize core competencies and gain competitive advantage (Hitt et al., 1995; Johnson et al., 2010). There are two basic types of strategies: core (base) and functional (Stabryła, 2000). Functional strategies are concerned with decisions within an enterprise to increase the efficiency of its operations. Baseline strategies determine the overall approach a company takes to compete.

These can include, for example, the following:

- cost strategy,
- quality leadership/differentiation strategy,
- leading strategy,
- market niche strategy.

Strategies implemented in the global market involve diversification along two dimensions: industry and international. In the industry dimension, activities are undertaken in horizontal, vertical, concentric or conglomerate arrangements, and are related to the selection and management of markets for different products. Strategies implemented in the international dimension involve locating activities outside the home country and coordinating these activities on a global scale.

The literature distinguishes four basic models of corporate conduct. These strategies are generally referred to as cross-border or global (Yip, 1996). These strategies are:

- multinational,
- international,
- global,
- transnational.

The multinational strategy involves decentralization of decisions and delocalization of resources (Brock, Birkinshaw, 2004). Foreign subsidiaries have a high level of autonomy. This strategy is based on a strong differentiation of foreign markets served by individual subsidiaries. Their task is to adapt production to the needs of host country markets. Most suitable when there is strong pressure on adjustment and low pressure on costs (Zorska, 2002).

The international strategy involves diversification by product and by country/market (Hitt et al., 2016). Product diversification involves producing differentiated product assortments in individual foreign subsidiaries, tailored to regional requirements. Domestic/market diversification implies the use of different locations for specific operational activities (different for sourcing, production, sales). The autonomy of international subsidiaries is much lower than that of multinational subsidiaries.

The global strategy is characterized by integrated and coordinated activities on a global scale. It is applicable in markets where local customization requirements are low and there is strong pressure to reduce costs. The large scale of production in regions with optimal conditions for manufacturing (e.g., low-cost raw materials and labor) makes it possible to reduce costs and improve the company's position. The global strategy, compared to the previous ones, is characterized by less product adaptation to local markets, but a much higher degree of operational integration and stronger pressure on costs (Stonehouse et al., 2001).

The transnational strategy integrates the international and global strategies (Donaldson, 2009). It attempts to coordinate and standardize operations in both product and domestic market arrangements. It exhibits greater adaptation to local requirements than the global strategy. The main instruments for implementing this strategy are the decomposition of the value chain, the geographic dispersion of functions and the units carrying them out. This strategy is accompanied by standardization and specialization, integration and coordination.

The above strategies describe ways to serve foreign markets. Early studies argued that internationalization is a slow process, and is evolutionary in nature (Johanson, Wiedersheim-Paul, 1975; Johanson, Vahlne, 1990). The typical course of this process is initiated by export. The next phase is various forms of cooperation. Finally, foreign direct investments are undertaken. Such a course is known as the *Uppsala model*. In addition to the intensity of foreign linkages, researchers Caves (1982), Davidson (1982) and Root (1987) argue that an important criterion for distinguishing forms of internationalization is the level of control exercised.

There is no unanimity on the number of forms of internationalization. For example, Buckley (1996) distinguishes: export, non-capital (contract) cooperation and capital cooperation. Otta (1994), in turn, distinguishes: export-import, cooperative ties (capital, non-capital, strategic alliances), and running business independently. Certo and Peter (1998) point to four methods of foreign expansion: export, licensing, joint ventures and direct investment, while Hill and Johns (2007) distinguish five of them: export, licensing, franchising, joint ventures, and direct investment.

Regardless of the differences in the course of the internationalization process, the number of forms and the type of strategies for serving foreign markets, all the enterprises implementing it share one common characteristic. In each case, various activities and resources of the enterprise are shifted outside the home country. As a result, a certain portion of sales is made in the company's home country while another portion is made outside its borders. A part of production may also be carried out outside the country, as well as research and development activities. As a result of internationalization, some of the enterprise's resources are shifted outside the home country. This observation makes it possible to try to measure the intensity of a company's foreign linkages. That is, to examine the level of its internationalization. In the next part of the paper, an attempt is made to systematically describe the most universal methods of measuring the internationalization of enterprises' activities.

4. Measurement of globalization and internationalization

Globalization takes place at three levels:

- world economy,
- industry/sector,
- enterprise.

4.1. Measurement of the globalization of national economies

Progressive globalization is characterized by the growth of certain indicators. Among the most important are (Krugman, 1995):

- the share of world exports in world GDP,
- the growth rate of foreign direct investment in the world relative to the growth rate of world GDP,
- the growth rate of gross investment in the world.

Studies show the relationship between economic growth and the integration of countries. Presented, for example, in the *World Bank Policy and Research Bulletin*, the integration index expresses the importance of international flows of goods and foreign direct investment to a country's economy. This index describes the degree of participation of a particular country in the globalization process. It is built on the basis of four other indicators (Dunning, 1993):

- index of trade share in GDP,
- ratio of foreign direct investment to GDP,
- index of investment risk,
- share of manufactured goods in exports.

There have been many attempts to measure globalization over the years. The main problem with such studies is that they require data and information that is difficult to access, expensive or not published periodically. Therefore, there are few reputable, methodologically sophisticated, systematically published globalization rankings. One exception is the *KOF Index of Globalization*. This is an index of the degree of globalization of countries published by the Eidgenössische Technische Hochschule (ETH). The original version of the index was developed by Dreher (2006). It is based on three main criteria: economic, political and social. The index covers the period since 1970 and currently contains 203 entries (including entities not officially recognized by the UN as countries, of which there are currently 195). Revisions of the index took place in 2008 and 2019. The new index is more extensive, including 43 variables compared to the last version's 23 variables. The revised version of the index (Savina et al., 2019) proposes two additional globalization indexes: *de facto* and *de jure*. The de facto globalization index measures actual flows and activities, while the de jure globalization index measures the policies and conditions that enable and support flows and activities. The overall *KOF Globalization Index* is an amalgamation of the previous two.

Another indicator of globalization is the *Maastricht Globalisation Index* (MGI), developed in 2009. The MGI, unlike the *KOF Globalisation Index*, takes into account environmental factors. The index was last revised in 2016 (Figge, Martens, 2016).

The *Globalization Index* was jointly developed by the international consulting firm A.T. Kearney and the bimonthly political and social magazine *Foreign Policy Magazine*. It was published from 2001 to 2007. The index measured countries in terms of their economic, technological, political and social integration.

Another tool was developed by the Center for the Study of Globalization and Regionalisation, Warwick University. It measured the economic, social and political dimensions of globalization of individual countries using sub-indices, which in aggregate form build the overall globalization index. The index was calculated for the years 1982-2004.

The *Globalization Index* was jointly developed by Ernst & Young and the Economist Intelligence Unit in 2009, and was updated in 2012 (Ernst & Young, 2013, pp. 30-34). The Index is based on a comprehensive survey of five main areas: openness to trade, capital flows, technology exchange, labor flows and cultural integration. The study covered the 60 largest countries for the period falling between 1995 and 2012.

The methodology for measuring globalization is constantly being developed by scholars of various disciplines, in particular: economics, sociology and economic geography (Andersen, Herbertsson, 2003; Bobek, Vide, 2005; Raab et al., 2008; Arribas et al., 2009; Houseman, Mandel, 2015). An overview of new directions in the construction of globalization indices is presented in the article by Martens and others (2015).

The aggregated indices presented are a powerful tool for capturing, illustrating, monitoring and communicating such a complex and multidimensional issue as globalization. However, it is important to note that constructing indices involves numerous subjective decisions made

by their authors. An important observation is also that globalization can only be measured indirectly, so there is no single correct or objective way to measure it, and therefore these subjective methodological choices must be transparent.

4.2. Measurement of the globalization of sectors

A company does not operate in a vacuum, but in the immediate environment of other companies that are engaged in the same core activity; that is, that produce goods or services with a similar purpose. They form a sector (Šmid, 2010, p. 216). To assess the attractiveness of a sector and determine the competitive position of an enterprise, methods of strategic analysis are used, primarily sector structural analysis. The position of the company in the sector can be determined by the strategic balance method and portfolio methods: the BCG matrix, McKinsey matrix, ADL matrix, SWOT analysis model. The assessment of the strategic situation is based on the following methods: scenario analysis, value chain model, Porter's Five Forces model. These methods should be used to assess the attractiveness of sectors in foreign markets.

Measuring the globalization of a sector requires the formulation of assumptions different from those of classical strategic analysis and the application of alternative methods, techniques and tools. The initial assessment of a sector should begin with an analysis of the importance and strength of the factors that either lead to or are a consequence of the internationalization of a company. These processes interact and reinforce each other. Another important remark is that sector assessment should be conducted at the national level. It may also be supplemented by an analysis of regional markets. The following are of particular importance in measuring the level of globalization:

- factors shaping the overall globalization process,
- strategies of companies using internationalization strategy.

Identification of globalization factors makes it possible to compare the globalization potential of different sectors or a specific sector over time. Measuring the level of these factors enables the determination of the directions and scope of necessary changes in the enterprise. According to Yip's (1996) concept, four groups of factors influence the process of internationalization of a sector:

- market,
- cost,
- government,
- competitive.

Some of these measures can be quantified, others require qualitative assessments.

Market factors include the homogeneity of customer needs, which is a difficult factor to measure. Customer needs may differ across countries. It is key to assess whether a product in its unchanged form can be supplied to different markets. If not, it is necessary to estimate the cost required to produce a product acceptable to the customer in a given market compared to the cost of manufacturing a globally standardized product. Distribution channels are much

easier to measure. A factor referred to as transferable marketing can be measured by the degree of customer acceptance of foreign *marketing-mix* elements, i.e. company name, brand name, packaging, advertising and promotion. The method of measurement for leading countries, on the other hand, can be based on the consideration of a certain number of recent, most significant innovations in a given sector.

Cost factors, despite their numerical nature, are difficult to obtain, particularly on a sector-wide scale. Economies of scale and scope can be estimated by calculating the minimum global market share required to achieve the minimum production scale that ensures profitability. Regarding the learning and experience curve, an indicator popularized by the Boston Consulting Group is applicable. It measures the effect of learning and experience as the percentage decrease in costs with each doubling of accumulated expertise. The measure of procurement efficiency, on the other hand, is the hypothetical percentage reduction in purchasing costs caused by central sourcing. To identify the cost differentiation of countries, the production costs of the most expensive country are compared with those in the least expensive one. The globalization potential of a sector can be estimated using the share of the total development cost (excluding marketing costs) of a new product. Another indicator for this group of factors is technology volatility, which can be measured by the length of the typical product life cycle in the market.

Another group of factors are government factors. They reflect the degree of favorable trade policies of host countries. They are evidenced by the levels of tariffs, subsidies and non-tariff barriers. The latter can be measured by the extent of import blockades. The level of comparability of technical standards can be measured by the ratio of the cost of manufacturing globally compatible components that make up a product to the total cost of manufacturing that product. The uniformity factor of marketing regulations, on the other hand, can be estimated by comparing the marketing costs incurred for marketing activities applicable in all countries to the total marketing costs of a company.

The group of competitive factors includes, among others, exports and imports. Their level is determined by examining the share of the home country beyond its borders relative to the global total. This group also includes the factor of production concentration. International enterprises, whose nature of business requires the maximum utilization of economies of scale, are forced to concentrate production, while aiming to sell in as many markets as possible. The interdependence of countries can be measured by adding up the volume of sales from participating manufacturers and dividing it by the total sales volume of a global competitor. Measuring the level of global competition is possible by estimating its level using the measures of global strategy instruments discussed next. These factors are summarized in Table 1.

Table 1.
Overview of sector globalization indicators

Factor	Indicator
MARKET	
Homogeneous needs	• The degree of similarity in customers' needs worldwide. • The percentage share of global common element costs in total product manufacturing costs.
Global customers	Share of the global sales volume accounted for by customers seeking suppliers worldwide.
Global distribution channels	Share of distribution networks based on centralized purchasing in global sales volume.
Transferable marketing	Share of foreign countries where elements of the marketing mix are accepted (applied to each element of the marketing mix).
Leading countries	Number of countries most significant in innovation creation.
COST	
Economies of scale and scope	Share of the world market that ensures a minimum (from the point of view of profitability) scale of production or services.
Learning and experience	Percentage reduction in costs calculated per unit of production following a doubling of accumulated skills.
Sourcing efficiencies	Potential percentage savings obtained from doing all purchasing centrally.
Favorable logistics	Percentage share of transportation costs on standard intercontinental routes in sales prices.
Differences in country costs & skills	The ratio of the cheapest to the most expensive countries in a given sector for: • hourly labor cost, • total unit cost of production.
Product development cost	The cost of developing a new product or service, calculated as a share of the sales value realized throughout the product lifecycle.
Fast-evolving technologies	Life cycle length of a new typical product on the market.
GOVERNMENT	
Effects of tariffs	Calculated as a share of the sales price before customs duties, in a global average
Effect of subsidies	• Average global share in the sales price before subsidy. • Net percentage impact of subsidized competitors on the sales price.
Non-tariff bariers	Global market size not available for imports (in %).
Compatible technical standards	Percentage of the cost of technically compatible components in the total cost of a typical product (worldwide).
Common marketing regulations	The share of a sector's worldwide marketing expenditures spent on marketing activities allowed in each country.
State-owned competitors	The total global market share of all competitors that are state-owned.
State-owned customers	The total share of global sector purchases made by state-owned entities.
COMPETITIVE	
Export	Percentage share of exports in the global market.
Import	Percentage share of imports in the global market.
Competitors from different continents and countries	The number of continents that serve as home markets for global competitors.
Interdependence of countries	Sales volume (in each country) dependent on production from factories serving more than one market (average calculated for all competitors).
Competitors globalized	The degree of adoption of global strategy tools by competitors.

Source: Yip, 1996, p. 261 and following.

4.3. Measurement of the globalization of sectors

The following measures can be used to examine the level of globalization of the sector:

- global market participation,
- global products,

- global location of operations,
- global marketing,
- global competitive moves.

Time-based comparisons of these metrics allow for determining the dynamics and directions of change of the global strategy applied by the enterprise. Comparing them with competitors enables the identification of competitive opportunities and threats.

The global market participation index is calculated by determining the ratio of a specific enterprise's activity to the total global volume of that activity conducted by all companies in the sector. In order for an enterprise to participate fully in the global market, it must be present in markets of strategic importance. It is therefore important to examine participation in these markets. This can be done by assessing the level of sustainability of participation in that market. For this assessment, it is necessary to compare the percentage distribution of sales in a given sector with the distribution resulting from the activity of the enterprise under analysis. If they overlap, this indicator will take the value of 1; in the case of a complete discrepancy, the value of 0. The level of participation in the global market can be measured by the number of countries in which sales are made.

The level of use of global products can be measured by the degree of their standardization. If the share of standardized products of a given company in the total volume of production is 70%, this is the level the standardization index takes. If it is necessary to relate the measurement only to certain markets (for example, markets of strategic importance), the so-called static indicator of product standardization is used. For this purpose, the percentage of standardized products (X) in countries representing Y% of the global market volume is determined. The indicator is the product of X and Y.

A full assessment of the level of global localization of activities is possible after conducting an analysis of:

- the concentration of a given business activity,
- the concentration of the value chain,
- the production location matrix.

Comparing the distribution of revenues with the distribution of costs, based on geographic criteria, allows for assessing the level of business concentration. To assess the level of concentration of the entire value chain, such a comparison should be carried out for the individual activities that make up the chain. The development of a production location matrix makes it possible to identify product flows and demonstrate the degree of dependence of sales on individual local factories.

Qualitative indicators are primarily used to assess global marketing. Quantitative measures include the marketing intensity index, which is calculated as the standard deviation of the input-sales relationship in each of the countries analyzed and for each marketing element. Determining the uniformity of marketing elements is possible by calculating the degree of

similarity between the marketing elements used in each country and those used in the home country.

Global competitive moves can be reflected by measuring the frequency of a company's response to attacks from competitors, while the degree of coordination of competitive moves can be reflected by the number of countries participating in each sequence of these moves.

These measures are summarized in Table 2.

Table 2.
Instruments of the global strategy

Instrument	Indicator
PARTICIPATION IN THE GLOBAL MARKET	
Global Market Share	The global business volume of the enterprise divided by the total global market volume.
Strategic Market Share	The business volume of the company in markets of countries with global strategic significance, divided by the total volume of these markets.
Balancing Global Market Share	Comparison of the percentage distribution of the company's revenues with the percentage distribution of revenues on the global market.
Market Presence	The number of countries in which the company conducts sales.
Global Market Coverage	The share of global sales volume from the markets of countries where the company conducts sales.
GLOBAL PRODUCTS AND SERVICES	
Product-Mix Standardization	Percentage share of global sales revenue from standardized products or services.
Product Characteristic Standardization	Percentage share of standardized elements in the product or service cost.
GLOBAL LOCATION OF ACTIVITIES	
Concentration of a Given Activity	Share of global expenditures incurred in the country where the largest portion of the given activity is located
Concentration of the Entire Value-Added Chain	Weighted average of the concentration indicators for individual links in the value chain.
GLOBAL MARKETING	
Comparison of Marketing Intensity	The intensity of marketing activities in individual countries.
Standardization of Marketing Elements	The degree of similarity between the marketing elements used in each country and those used in the home country.
Overall Marketing Standardization	An index calculated for each element, weighted by the share of revenues obtained by the company in each country and the significance of each element.
GLOBAL COMPETITIVE MOVES	
Multinational Competitive Moves	Moves involving three or more important countries.
Counterattacks	Responding to a competitive attack in a given country by undertaking actions in other countries.

Source: Yip, 1996, p. 271 and following.

4.4. Measuring the foreign involvement of the enterprise

So far, various approaches and ways of determining globalization and internationalization of national economies and sectors have been discussed. The rest of the article describes how to measure a company's foreign involvement, that is, the globalization of a company and the internationalization of a company's operations.

4.4.1. Measuring the globalization of the enterprise

The indicators presented in the previous subsections allow to determine the level of globalization of the sector and the globalization of the enterprise's strategy. In addition to this, it is possible to examine the degree of globalization at the level of the economic unit. The degree of adaptation of the enterprise to the global market can provide information about the overall level of internationalization. Including the time factor in the analysis makes it possible to assess the dynamics of the internationalization process.

Measures of the globalization of the organization are overwhelmingly qualitative, and the assessment of the degree of globalization of the entity obtained from them is descriptive. The assessment of foreign involvement is made in strategically important areas of the company, i.e. its organizational structure, management processes, human resources and organizational culture. In general, a qualitative study enables an explanation of an enterprise's development in relation to changes in its surrounding environment. It answers the question to what extent the enterprise is adapted to the global market, what position it occupies in the sector undergoing globalization processes and to what extent its base strategy coincides with the global strategy (globalization of operations).

The most important measures of the degree of globalization of an enterprise are presented in Table 3.

Table 3.
Indicators of the degree of an enterprise's globalization

Organizational Element	Indicator
ORGANIZATIONAL STRUCTURE	
One Global Manager	Is there a designated person whose primary responsibility is leading the global enterprise?
International branch	Are there branches of the enterprise that limit their activities to their home market?
Functional line management	Is there one line manager leading each functional area?
Functional staff management	Is there a coordinator position for each functional area?
Importance of the "enterprise" dimension	This measure refers to the strength of the "enterprise" dimension in terms of the geographic and functional dimensions.
MANAGEMENT PROCESSES	
Global strategic information system	The degree of formal standardization and regularity of the collection of strategic information from around the world.
Cross-country coordination	Scope of cross-country strategy coordination (information exchange, negotiating plans, aligning plans).
Global strategic planning	Degree of effective strategic integration of international planning processes.
Global budget	The degree of globalization of global program budgets.
Global evaluation and reward systems	The degree to which global achievements are used as a criterion for evaluating senior management.
PEOPLE	
Foreign nationals in a given country	Percentage of senior managers in a given country who are foreign nationals.
Citizens of a given country in another country	Percentage of senior managers from a given country working in other countries as foreign nationals.
Foreign nationals in other countries	Percentage of senior managers in other countries who are foreign nationals there.

Cont. table 3.

CULTURE	
Global culture	To what extent is the culture of a corporation or enterprise more global than national?
Cultural interdependece	To what extent does the culture foster more interdependence than autonomy?

Source: Yip, 1996, pp. 278-279.

The proposed indicators, however, do not provide a definitive measure of an enterprise's degree of internationalization. The lack of objective criteria makes it very difficult to compare individual companies. These questions are attempted to be answered in the following section of the paper.

4.4.2. Measuring the degree of internationalization of an enterprise's operations

There are various proposals in the literature for measuring the degree of internationalization. For example, there are proposals that recommend analyzing as many elements that describe the process as possible. Such an approach works well for observing a specific enterprise over a certain period of time. However, it is of limited use in comparative analysis. Mainly due to the difficult availability of relevant data. To eliminate this disadvantage, other proposals have been developed. These, in turn, take into account few elements through the prism of which internationalization is studied, but ones that are relatively easy to obtain. This approach has been criticized mainly for its poor description of the causes and course of internationalization. The following section presents the most widely represented proposals in the literature for measuring the level (degree) of this phenomenon

4.4.2.1. Preliminary assumptions

Internationalization, understood as the transfer of economic activity abroad, allows for considering it as a function of foreign activity of the enterprise. As a result, changes occur (in the country/foreign context) in many areas of the enterprise's operations. This is revealed in changes in the structure of: sales, production, assets, employment and organizational structure. The usefulness of information on these areas depends on whether they are quantifiable on a country/foreign basis and whether they are significantly related to internationalization. Elements that meet these conditions are called internationalization features. A feature is a random variable whose values, assigned to individual items of the studied population, vary randomly. Thus, the feature takes different values for items of the same kind (enterprises) occurring under the same conditions. The inclusion of less important features in the calculations may result in the risk of obtaining unreliable results. However, it should be noted that it is very difficult to categorically determine the impact of the proposed features on the overall level of internationalization. The greatest difficulty arises from the intermingling of several factors that affect internationalization and which influence this process in different directions with varying strength. The overall level of internationalization consists of the coexistence of a set of features, which, through their interconnections, trigger very strong but difficult-to-directly observe interactions.

A separate research problem is the inclusion of too few or, conversely, too many features in the study. Too few may give rise to the accusation of inadequate description of the phenomenon under study, while too many complicate its evaluation and the determination of the true significance of the process under study. In the literature, two groups of indicators are most often used to study the internationalization of enterprises:

- unit indicators (analytical) – these are indicators that serve as individual measures of specific areas of the enterprise's operations,
- aggregated indicators (composite/synthetic) – these are indicators constructed from individual analytical indicators.

Dörrenbächer (2000, p. 120) additionally distinguishes measures of spatial international diversification (regional concentration, networked organization, geographical and cultural distance).

Internationalization profiles are a specific group of indicators. This is a graphical method of presenting the level of a company's internationalization.

4.4.2.2. Analytical indicators

The first proposals for measuring internationalization used analytical indicators. Measurement should begin by defining the features of the process. They can be divided into state (relatively constant) features and variable quantities. State quantities include (Macharzina, Welge, 1989, p. 966):

- number of plants,
- value of invested capital,
- value of capital (own and foreign),
- number of employees,
- number of board members,
- number of shareholders.

The variable quantities are:

- volume of capital expenditures/value of investments,
- volume of research and development expenditures,
- value of manufactured products,
- number of manufactured products,
- volume of sales revenues,
- volume of employee compensation,
- volume of interest paid,
- volume of taxes,
- financial result.

An important tool for describing and interpreting economic phenomena is ratio analysis. It allows for the examination of the current state of specific phenomena occurring in the economy or enterprise and reveals the trends taking place within them. An appropriately selected set of indicators can help assess the intensity of internationalization. Among the most important ones are (Rymarczyk, 1996, pp. 21-22):

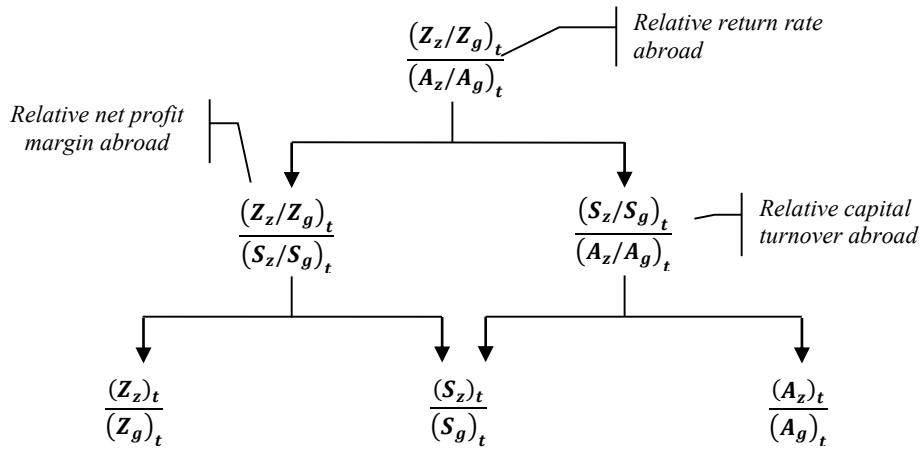
- number of foreign markets served,
- share of book value of assets abroad in the total assets of the enterprise,
- share of turnover in the total turnover of the enterprise,
- share of foreign profits in the global profit of the enterprise,
- forms of foreign involvement in value or volume terms (e.g., exports, license sales, franchising, foreign subsidiaries, subsidiaries),
- size of foreign direct investment (absolute or in relation to the total investment of the enterprise),
- shares in foreign markets,
- share of foreign employees in global employment.

The actual volumes related to operations in the home country and abroad allow for the calculation of the "foreign volume" for individual characteristics, which in this paper will be referred to as the "foreign share". It is calculated using the formula:

$$foreign\ share\ in\ turnover = \frac{foreign\ turnover}{global\ turnover} \cdot 100\%$$

To assess the level of internationalization, one can also use certain systems of indicators containing defined links between individual indicators. An example may be the widely used in financial analysis ROI (*Return on Investment*) indicator and its representation using the Du Pont formula (see: Macharzina, Welge, 1989, p. 966). The first version of the formula shows the rate of return on invested capital expressed as the product of the net profit margin and the overall turnover rate. The possibility of its use in internationalization analysis is presented in Figure 1.

Internationalization is described here by the relationship between specific quantities in the home country and abroad. This is obtained by dividing certain volumes (e.g., profit, capital, revenue) achieved outside the country by their global counterparts. This yields so-called relative volumes. The results obtained can be used as a tool for inference according to the principle: the greater the relative rate of return, relative profitability and relative turnover of capital abroad, the greater the degree to which the company is internationalized.



Where:
A_g – global assets,
A_z – assets located abroad,
S_g – global sales,
S_z – sales generated abroad,
Z_g – global profit,
Z_z – profit generated abroad,
t – point in time at which internationalization is measured.

Figure 1. Relationships between factors shaping ROI in international business.
Source: Macharzina, Welge, 1989, p. 966.

Information on the activities of competitors can also be included in the calculations, creating the appropriate benchmark values according to the formula:

$$relative\ size\ of\ foreign\ market\ share = \frac{foreign\ market\ share}{domestic\ market\ share} \cdot 100\%$$

Internationalization can be studied by observing nominal values over time. For the purpose of comparative observation of internationalization, certain measurement values can be used. They can be defined as follows:

$$foreign\ turnover\ measurement = \frac{foreign\ turnover\ (t)}{foreign\ turnover\ (0)} \cdot 100\%$$

$$domestic\ turnover\ measurement = \frac{domestic\ turnover\ (t)}{domestic\ turnover\ (0)} \cdot 100\%$$

These values allow for the calculation of the relative growth size of foreign turnover for the time period from 0 to t, expressed by the formula:

$$relative\ growth\ size\ of\ foreign\ turnover = \frac{foreign\ turnover\ measurement}{domestic\ turnover\ measurement} \cdot 100\%$$

4.4.2.3. Aggregated indicators

In addition to the discussed analytical indicators, indices, which are indicators derived from the aggregation of unit indicators, can also be used to study internationalization. Among the best known are:

- DOI (*Degree of Internationalization*).
- TNI (*Transnationality Index*).
- TASI (*Transnationality Activity Spread Index*).

The DOI index was developed by Sullivan (1994; 1996) as a result of observing 74 American transnational corporations with a production focus. The index is a combination of variables that characterize, in a country/foreign context:

- sales structure,
- asset structure,
- branch location structure,
- foreign experience of the management team.

The index takes values from 0.0 (no international activity at all) to 5.0 (doing business exclusively outside the home country). It consists of five unit indicators, which are:

- FSTS (*Foreign Sales as a Percentage of Total Sales*):

$$FSTS = \frac{FS}{TS} \cdot 100\%$$

where:
FS – *Foreign Sales*,
TS – *Total Sales*.

- FATA (*Foreign Assets as a Percentage of Total Assets*):

$$FATA = \frac{FA}{TA} \cdot 100\%$$

where:
FA – *Foreign Assets*,
TA – *Total Sales*.

- OSTS (*Overseas Subsidiaries as a Percentage of Total Subsidiaries*):

$$OSTS = \frac{OS}{TS} \cdot 100\%$$

where:
OS – *Overseas Subsidiaries*,
TS – *Total Subsidiaries*.

- TMIE (*Top Manager's International Experience*) – an index measuring the share of top managers' time working overseas to total managerial time.
- PDIO (*Psychic Dispersion of International Operations*) – an index measuring the dispersion of overseas operations within zones that differ in terms of so-called psychic distance. Each of the identified zones, as suggested by Adler et al. (1986) and Hofstede (1993), has a unique “cognitive map” of management principles. This assumes that the greater the dispersion of a company's subsidiaries in these zones, the greater the mental distance of its international operations.

The aggregated indicator takes the form of:

$$DOI = FSTS + FATA + OSTS + TMIE + PDIO$$

Aggregated indices have an advantage over indices that describe only one area. They take into account several areas, but return only one numerical value. This makes it easier to compare and observe index values over time. However, there are risks associated with selecting the right areas and assuming the strength of their influence on a given phenomenon. The DOI index is a non-weighted index. Such an index is characterized by the uniform importance (or rank) of each constituent element. It is not infrequently the origin of criticism. In accordance with the model of internationalization, the enterprise commences its expansion from the stage of sales. In the course of the present stage, a number of enterprises conclude their internationalization efforts and do not progress to more advanced forms of internationalization, such as direct investments. Greater investment is required in terms of capital, and a higher level of coordination is also necessary. In accordance with this assumption, it is recommended that each element be assigned a different degree of importance.

The *Transnationality Index* (TNI) was developed by researchers (including Dunning, Cantwell, Kim, Kumar, Wells, Young) associated with the *Division on Transnational Corporations and Investment* – an agency of UNCTAD (*United Nations Conference on Trade and Development*). The index was first published in 1995 in the *World Investment Report*. The authors assumed that internationalization can be described as a function of an enterprise's foreign activity. This allows for its examination through the analysis of selected variables that can characterize this process. It was assumed that these variables are the value of sales, the value of assets and the amount of employment achieved in foreign markets in relation to the total size of these parameters. The TNI index is built from three sub-indices:

$$ITA = \frac{FA}{TA} \cdot 100\%$$

where:
ITA – index of transnationality of assets,
FA – foreign assets,
TA – total assets.

$$ITS = \frac{FS}{TS} \cdot 100\%$$

where:
ITS – index of transnationality of sales,
FS – foreign sales,
TS – total sales.

$$ITE = \frac{FE}{TE} \cdot 100\%$$

where:
ITE – index of transnationality of employment,
FE – foreign employment,
TE – total employment.

The TNI index is calculated as the arithmetic mean of the partial indices:

$$TNI = \frac{ITA + ITS + ITE}{3}$$

The TNI index is probably the most important and most widely used measure of an enterprise's internationalization at present (Przybylska, 2006, p. 43; Wach, 2016, p. 115). This is certainly supported by the authority of its creators and the reputation of the institution that endorses the index. The mentioned elements suggest a high methodological quality, as well as the reliability of input data and calculations. The cyclical nature of the index's release and its methodological continuity also play a significant role.

The disadvantage of the indicator is that it does not take into account the number of countries in which the company operates, their size and strategic importance. The index only captures the relationship between activity in the home country and abroad.

This index shares a disadvantage with the one discussed earlier: it assigns equal weights to its components – sales volume, asset value, and employment size. As a result, two companies following fundamentally different internationalization strategies can achieve the same index value. For example, one company may have a high share of foreign sales but relatively low shares of foreign assets and employment. In contrast, another company might hold significant foreign assets and employ a large number of staff abroad, yet generate a relatively small portion of its sales from foreign markets. The index value does not reflect these strategic differences. A more nuanced understanding is possible, to some extent, through an analysis of the internal structure of the index.

Over time, the TNI has been expanded to include other indices (Wach, 2016, p. 116):

- NSI (*Network Spread Index*) – calculated as the quotient of the number of foreign markets (countries) in which an enterprise has subsidiaries and the number of foreign countries in which that enterprise could potentially have subsidiaries,
- *Internationalization Index* – expressed as a percentage, it is calculated as the number of foreign subsidiaries of a given enterprise divided by the total number of its subsidiaries,
- GSI (*Geographical Spread Index*) – calculated as the square root of the Internationalization Index multiplied by the number of countries in which the enterprise operates.

The NSI index was constructed by the same team as the TNI index. It considers internationalization through the lens of the number of countries in which the enterprise operates. It is also called the corporate networking index. It captures the relationship between the number of countries in which an enterprise locates its subsidiaries/branches and the number of all countries in the world receiving foreign direct investment (FDI), minus the home country. *World Investment Report 2022* indicates that there are 168 such countries out of 195 officially recognized by the UN.

The index takes the form of:

$$NSI = \frac{number\ of\ countries\ in\ which\ the\ company\ has\ subsidiaries/branches}{number\ of\ countries\ where\ FDI\ activities\ are\ undertaken - 1} \cdot 100\%$$

A large number of countries where subsidiaries/branches are located can mean high management costs for a company, high transaction costs, but also indicate a high level of ownership advantage. The main disadvantage of the index is that it does not take into account the size of countries. Each host country is given the same weight, regardless of the potential of its market, the size of the assets involved or the volume of sales or employment.

A correlation analysis of TNI and NSI conducted by authors from the *Division on Transnational Corporations and Investment* showed their low degree of interdependence. In addition, it was found that enterprises can internationalize their operations without stretching their activities to a large number of countries. Instead, they should focus on markets of the greatest strategic importance. The result of such a strategy is the possibility of achieving a high TNI index with a relatively low NSI indicator.

In summary, TNI and NSI capture different aspects of internationalization. The first one indicates the extent to which an enterprise is moving its core business activities across the borders of its home country, while the second one indicates its geographic reach. Both of these indicators, although in different ways, are a source of knowledge about the intensity of internationalization and the opportunities for building competitive advantages in the global market.

Ietto-Gillies (1998) criticized the TNI and NSI indices. TNI on its own reports only the degree of a company's foreign involvement, but says nothing about geographic scope. The NSI, on the other hand, independently reports the reach, but says nothing about the level of involvement. The researcher proposed to solve this problem by including both indices in the construction of another index, the TASI (*Transnational Activities Spread Index*). The structure is as follows:

$$TASI = TNI \cdot NSI$$

The low correlation coefficient between the indicators confirmed in studies (Hassel et al., 2003) indicates that they inform about different aspects of internationalization. This means that corporations with the highest degree of foreign involvement of their resources are not at the same time the companies with the greatest reach. For this reason, attempting to draw conclusions solely based on the TASI index, without its components, presents a certain issue. The same level of the index can occur in the case of a combination: a company with a strong commitment of resources and a low reach, and a company with a low commitment of resources and a high reach. These enterprises certainly cannot be considered similar, as their international situation is radically different.

4.4.2.4. Internationalization profiles

In addition to individual indicators, the level of internationalization can also be studied utilizing so-called internationalization profiles. This graphical method involves selecting features significant from the point of view of internationalization, calculating foreign shares for each feature, and then graphically presenting them in the form of a profile. Only those characteristics that are significantly related to internationalization, that is, either directly affect

it or directly result from it, should be qualified for the construction of the profile. Otherwise, there is a risk of obtaining unreliable results (Figure 2).

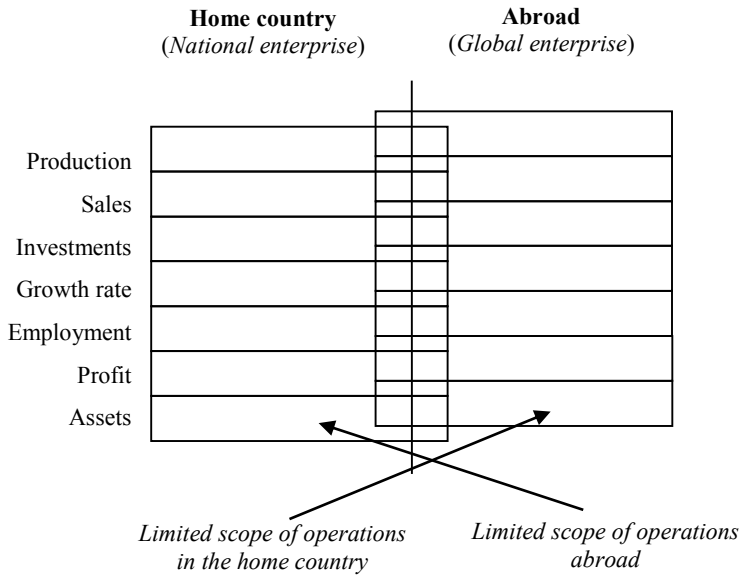


Figure 2. Ideal type of internationalization profile.

Source: Rymarczyk, 1996, p. 24.

The use of the profile to study internationalization involves analyzing its center of gravity. The further this point shifts towards foreign markets, the higher the degree of internationalization. Since some areas of activity undergo internationalization more strongly and rapidly than others, the actual type of profile will differ from the ideal one (Figure 3).

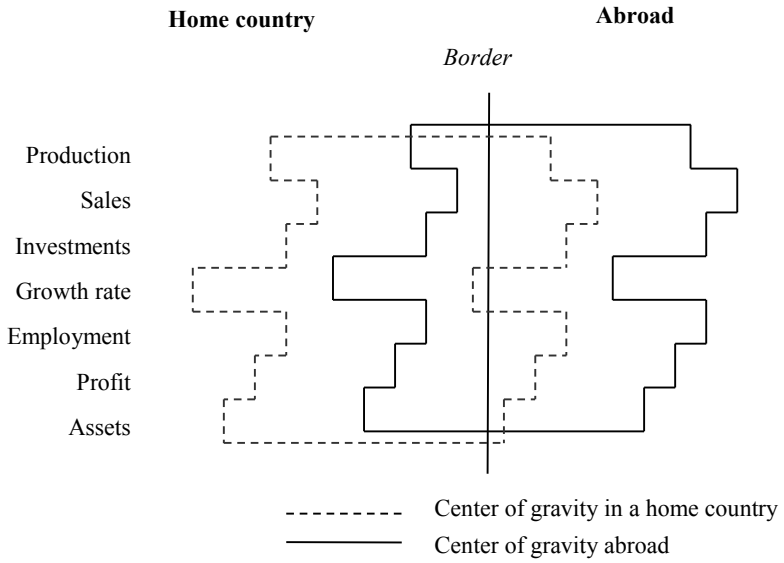


Figure 3. Real type of internationalization profile.

Source: Rymarczyk, 1996, p. 25.

Analysis of the internationalization profile allows for observing which types of activities are carried out with greater intensity and which with lesser intensity. Comparing profiles constructed based on data from different points in time allows for drawing conclusions about the dynamics of the company's foreign involvement and the leading strategy for market servicing (export, investment-based). Profiles can also be used for comparative analysis with other companies in the sector. In this sense, they can be an important tool to support the business management process.

5. Conclusions

The search for characteristics suitable for studying internationalization is based on the assumption that it is measured by the extent to which core business activities expand beyond the enterprise's home country. However, determining the impact of the proposed features on the overall level of internationalization is very difficult. The greatest difficulty arises from the interplay of multiple factors influencing the internationalization of enterprises, each affecting the process with varying strength and in different directions. The overall level of internationalization consists of the coexistence of a set of features that, due to their strong interconnections, create very powerful interactions that are difficult to observe directly. Specific levels of this phenomenon can result from a variety of causes, which include political changes, technological changes or changes in economic systems. The existence of a large number of characteristics that can be attributed to the internationalization process significantly complicates its assessment and the determination of the actual significance and impact they have on shaping this process.

The paper attempts to systematize and describe methods of measuring globalization processes at three levels: economies, sectors and enterprises. The descriptive measures presented in the paper, as well as indexes and profiles, allow a static view of internationalization.

None of the described ways of measuring internationalization is perfect or fully captures all aspects of the phenomenon under study. The indicated methods and assessment tools provide data and information that, when used correctly, meet the premises of objectivity, and this already makes them a tool that can be useful in the process of business management.

The paper contains only theoretical content. This convention has been adopted because, given the stated objective, illustrating with numerical data would require a significant expansion of the work. Undoubtedly, such works should be created, as there is a place for them in the economic literature. Of particular interest would be studies on the measurement of the dynamics of the internationalization process and the links between the level of internationalization and its efficiency.

References

1. Adler, N., Doktor, R., Redding, G. (1986). From the Atlantic to the Pacific century: Cross-cultural management reviewed. *Journal of Management*, *12, 2,* pp. 295-318.
2. Andersen, T.M., Herbertsson, T.T. (2003). Measuring globalization. *Discussion Paper*, *No. 817, July*. Retrieved from: http://ssrn.com/abstract=434540, 17.05.2024.
3. Andrews, K.R. (1987). *The concept of corporate strategy.* Homewood: Irwin.
4. Ansoff, H.I. (1965). *Corporate strategy; an analytic approach to business policy for growth and expansion*. New York: McGraw-Hill.
5. Arribas, I., Pérez, F., Tortosa-Ausina, E. (2009). Measuring globalization of international trade: theory and evidence. *World Development, 37, 1,* pp. 127-145.
6. Baker, S.R., Bloom, N., Davis, S.J. (2016). Measuring economic policy uncertainty. *The Quarterly Journal of Economics*, *131, 4,* pp. 1593-1636.
7. Barney, J. (1991). Firm Resources and Sustained Competitive Advantage. *Journal of Management*, *17, 1,* pp. 99-120.
8. Barney, J., Wright, M., Ketchen, D.J. (2001). The resource-based view of the firm: Ten years after 1991. *Journal of Management*, *27, 6,* pp. 625-641.
9. Binnis, A., Harreld, J.B., O'Reilly, C. III, Tushman, M.L. (2014). The art of strategic renewal. *MIT Sloan Management Review*, *Winter*, pp. 21-23.
10. Bobek, V., Vide, R.K. (2005). The signification and the feasibility of measuring globalization of economy. *Industrial management & Data Systems*, *105, 5,* pp. 596-612.
11. Brock, D., Birkinshaw, J. (2004). Multinational strategy and structure: A review and research agenda. *Management International Review*, pp. 5-14.
12. Buckley, P.J. (1996). The role of management in international business theory: A meta-analysis and integration of the literature on international business and international management. *Management International Review*, *36*, pp. 7-54.
13. Caves, R.E. (1982). *Multinational enterprise and economic Analysis*. Cambridge: Cambridge University Press.
14. Certo, S.C., Peter, P.J. (1998). *Strategic management: Concepts and applications*. New York: Random House Inc.
15. Davidson, W.H. (1982). *Global strategic management*. New York: John Wiley.
16. Donaldson, L. (2009). In search of the matrix advantage: A reexamination of the fit of matrix structures to transnational strategy. In: J.L.C. Cheng, E. Maitland, S. Nicholas (Eds.), Managing subsidiary dynamics: Headquarters role, capability development, and China strategy. *Advances in International Management, 22.* Bingley: Emerald Group Publishing Limited, pp. 3-26.
17. Dörrenbächer, C. (2000). Measuring corporate internationalization: A review of measurement concepts and their use. *Intereconomics, 35, 3,* pp. 119-126.
18. Dreher, A. (2006). Does globalization affect growth? Evidence from a new Index of Globalization. *Applied Economics*, *38, 10,* pp. 1091-1110.

19. Dunning, J.H. (1993). *Multinational enterprises and the global economy*. Workingham: Addison-Wesley.
20. Ernst & Young (2013). *Looking beyond the obvious. Globalization and new opportunities for growth*. Retrieved from: https://www.yumpu.com/en/document/read/51442670/looking-beyond-the-obvious-globalization-and-new-opportunities-for-, 20.05.2024.
21. Figge, L., Martens, P. (2016). Globalisation continues: The Maastricht Globalisation Index revisited and updated. In: R. Cörvers, J. de Kraker, R. Kemp, P. Martens, H. van Lente (Eds.), *Sustainable development research at ICIS: Taking stock and looking forward*, Universiteit Maastricht, ICIS.
22. Grant, R.M. (1991). *Contemporary strategy analysis: concepts, techniques, application*. Cambridge: Blackwell.
23. Hill, C.W.L., Jones, G.R. (2007). *Strategic management theory: An integrated approach*. 7th ed. Boston: Houghton Mifflin.
24. Hitt, M.A., Ireland, R.D., Hoskisson, R.E. (1995). *Strategic management. Competitiveness and globalization concepts.* Minneapolis/St. Paul: West Publishing.
25. Hitt, M.A., Li, D., Xu, K. (2016). International strategy: From local to global and beyond. *Journal of World Business*, *51, 1,* pp. 58-73.
26. Hofstede, G. (1993). Cultural constraints in management theories. *Academy of Management*, *7, 1,* pp. 81-94.
27. Houseman, S.N., Mandel, M. (Eds.) (2015). *Measuring globalization. Better trade statistics for better policy*. Michigan: W.E. Upjohn Institute for Employment Research Kalamazoo.
28. Ietto-Gillies, G. (1998). Different conceptual frameworks for the assessment of the degree of internationalization: An empirical analysis of various indices for the top 100 transnational corporations. *Transnational Corporations*, *7, 1,* pp. 17-39.
29. Johanson, J., Wiedersheim-Paul, F. (1975). The internationalization of the firm – Four Swedish cases. *Journal of Management Studies*, *12*, pp. 305-322.
30. Johanson, J., Vahlne, J.E. (1990). The mechanism of internationalization. *International Marketing Review*, *7*, pp. 11-23.
31. Johnson, G., Scholes, K., Whittington, R. (2010). *Podstawy strategii*. Warszawa: PWE.
32. Kaplan, S., Orlikowski, W. (2015). Beyond forecasting: Creating new strategic narratives. *MIT Sloan Management Review*, Special Collection: Top 10 Lessons on Strategy, pp. 14-19.
33. Kaulich, F. (2012), *Diversification vs. specialization as alternative strategies for economic development: Can we settle a debate by looking at the empirical evidence?* Vienna: United Nations Industrial Development Organization (UNIDO).
34. Krugman, P. (1995). Growing world trade: Causes and consequences. *Brookings Papers on Economic Activity*, *26, 1,* pp. 327-377.
35. Krupski, R. (2006). Kierunki rozwoju ujęcia zasobowego zarządzania strategicznego. In: R. Krupski (Ed.), *Zarządzanie strategiczne. Ujęcie zasobowe* (pp. 53-64). Wałbrzych: Wałbrzyska Wyższa Szkoła Zarządzania i Przedsiębiorczości.

36. Macharzina, K., Welge, M.K. (1989). *Handwörterbuch Export und internationale Unternehmung*. Stuttgart: C.E. Poeschel Verlag.
37. Martens, P., Caselli, M., De Lombaerde, P., Figge, L., Scholte, J.A. (2015). New directions in globalization indices. *Globalizations*, *12, 2,* pp. 217-228.
38. McKiernan, P. (1997). Strategy past; strategy futures. *Long Range Planning*, *30, 5,* pp. 790-798.
39. Mintzberg, H., Quinn, J.B. (1996). *The strategy process: concepts, contexts and cases*. London: Prentice Hall.
40. Mintzberg, H., Quinn, J.B., Ghoshal, S. (1995). *The strategy process: Concepts, context and cases*. Englewood Cliffs: Prentice Hall.
41. Obłój, K. (2007). *Strategia organizacji. W poszukiwaniu trwałej przewagi konkurencyjnej*. Warszawa: PWE.
42. Otta, W. (1994). Strategia przedsiębiorstwa na rynkach zagranicznych. In: T. Gołębiowski (Ed.), *Przedsiębiorstwo na rynku międzynarodowym*. Warszawa: PWN.
43. Porter, M.E. (1980). *Competitive strategy: Techniques for analysing industries and competitors*. New York: The Free Press.
44. Prahalad, C.K., Hamel, G. (1990). The core competence of the corporation. *Harvard Business Review*, *May-June*, pp. 79-90.
45. Przybylska, K. (2006). Pomiar internacjonalizacji przedsiębiorstwa. *Gospodarka Narodowa*, *3*, pp. 41-57.
46. Quinn, J.B. (1978). Strategies for change: „Logical incrementalism". *Sloan Management Review*, *20*, pp. 7-21.
47. Raab, M., Ruland, M., Schönberger, B., Blossfeld, H.P., Hofäcker, D., Buchholz, S., Schmelzer, P. (2008). GlobalIndex: A sociological approach to globalization measurement. *International Sociology*, *23, 4,* pp. 596-631.
48. Root, F.R. (1987). *Entry strategies for international markets*. Lexington: Lexington Books.
49. Rumelt, R.P. (1991). How much does industry matter? *Strategic Management Journal, 12, 3,* pp. 167-185.
50. Rymarczyk, J. (1996). *Internacjonalizacja przedsiębiorstwa*. Warszawa: PWE.
51. Savina, G., Haelg, F., Potrafke, N., Sturm, J.E. (2019). The KOF Globalisation Index – revisited. *Review of International Organizations*, *14, 3,* pp. 543-574.
52. Shimizu, K., Hitt, M.A. (2004). Strategy flexibility: Organizational preparedness to reverse ineffective strategic decisions. *Academy of Management Executive*, *18, 4,* pp. 44-59.
53. Šmid, W. (2010). *Leksykon przedsiębiorcy.* Warszawa: Poltext.
54. Stabryła, A. (2000). *Zarządzanie strategiczne w teorii i praktyce firmy*. Warszawa: PWN.
55. Stonehouse, G., Hamill, J., Campbell, D., Purdie, T. (2001). *Globalizacja. Strategia i zarządzanie*. Warszawa: Felberg SJA.
56. Stonehouse, G., Pemberton, J. (2002). Strategic planning in SMEs – some empirical findings. *Management Decision, 40, 9,* pp. 853-861.

57. Sullivan, D. (1994). Measuring the degree of internationalization of a firm. *Journal of International Business Studies*, *25, 2,* pp. 325-342.
58. Sullivan, D. (1996). Measuring the degree of internationalization of a firm: A reply. *Journal of International Business Studies*, *27, 1,* pp. 179-192.
59. Verbeke, A., Asmussen, Ch.G. (2016). Global, Local or Regional? The Locus of MNE Strategies. *Journal of Strategies Studies, 53, 6,* pp. 1051-1075.
60. Wach, K. (2016). Pomiar internacjonalizacji przedsiębiorstwa z perspektywy przedsiębiorczości międzynarodowej. *Przedsiębiorczość i Zarządzanie*, *17, 10, 1,* pp. 109-126.
61. Yip, G.S. (1996). *Strategia globalna. Światowa przewaga konkurencyjna*. Warszawa: PWE.
62. Zorska, A. (2002). Strategie KMN na rynku wyrobów przemysłowych w Polsce. In: A. Zorska (Ed.), *Korporacje międzynarodowe w Polsce. Wyzwania w dobie globalizacji i regionalizacji*. Warszawa: Difin.

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MACROECONOMIC DETERMINANTS OF BANK MARKET VALUE: A REVIEW OF THE LITERATURE

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Purpose: The aim of this article is to conduct a structured review of empirical studies that examine the relationship between macroeconomic variables and the market value of listed banks. The review seeks to identify the most commonly studied macroeconomic factors, summarize the main empirical findings, and highlight methodological approaches used in the literature. By doing so, the article aims to assess the current state of research in this field, identify gaps and inconsistencies, and provide directions for future studies.
Design/methodology/approach: Review of the literature based on an analysis of empirical studies on the market valuation of banks.
Findings: Macroeconomic variables examined as determinants of the market value of banks include fundamental indicators such as GDP growth, inflation, interest rates, stock market indices, the unemployment rate, and the budget deficit. The market value of banks is also studied in relation to the quality of the institutional and legal environment, as well as in the context of systemic shocks. In each of these areas, the findings remain inconclusive, which highlights the need for further, more detailed research.
Research limitations/implications: The reviewed studies differ in terms of countries, time periods, and research methodologies, which may limit the comparability of findings and the ability to draw general conclusions.
Practical implications: This review may be useful for stock market investors, who can use observations of the macroeconomic environment to support their decisions regarding investments in bank stocks.
Originality/value: A key added value of this work is that it offers a literature review of existing studies on the relationship between macroeconomic variables and the market value of banks. It may help identify a research gap and support the design of further studies in this area.
Keywords: banks, macroeconomic factors, market value.
Category of the paper: literature review.

1. Introduction

Many banks operate as publicly listed companies, meaning their value is regularly determined on stock exchanges. The market value of listed banks is important not only for investors, but also for regulators and policymakers, as it reflects how the market perceives the financial health, risk, and growth prospects of these institutions. Since banks play a central role in every economy, understanding what drives their market value is especially important.

In contrast to non-financial companies, banks are subject to a unique set of regulatory constraints and are more tightly linked to monetary and fiscal policies. These institutional features make the valuation of banks particularly sensitive to changes in the macroeconomic environment. Macroeconomic factors such as GDP growth, inflation, interest rates, stock market performance, or policy uncertainty can significantly influence bank profitability, funding costs, and investor sentiment, thereby affecting the market value of these institutions.

Despite the potential importance of macro-level determinants, empirical research focusing specifically on the relationship between the macroeconomic environment and the market valuation of banks remains relatively limited. This review aims to fill this gap by analyzing empirical studies that explore the impact of macroeconomic variables on bank market value.

2. Scope and methodology of the literature review

A total of 27 empirical studies were analyzed in which the authors examined the impact of macroeconomic variables on the market value of banks. The relatively small number of articles stems from the fact that the literature on the relationship between the macroeconomic environment and bank market valuation is significantly limited compared to studies focusing on non-financial companies.

The empirical studies listed in Table 1 were conducted on highly diverse samples in terms of geographic coverage and time periods. The research spans both developed and developing countries across multiple regions, including Europe, North America, the Middle East, Asia, and Africa. The analyzed periods range from the late 1980s to the early 2020s, allowing for the inclusion of various phases of the economic cycle. This diversity reflects the complexity of studying macroeconomic influences on bank valuation and highlights the need for context-specific interpretations of empirical findings.

Table 1
Overview of empirical studies examining the relationship between macroeconomic factors and bank market value across countries and time periods

Authors (year)	Countries/Regions	Period
Alharbi et al. (2022)	14 countries from the Middle East and Southern Asia	2007-2017
AlKhouri, Arouri (2019)	6 countries from The Gulf Cooperation Council	2003-2015
Alouane et al. (2022)	Tunisia	2008-2017
Alyosef et al. (2019)	Kuwait	2009-2016
Caprio et al. (2007)	44 countries	2001
De Jonghe, Vennet (2008)	15 EU15 countries	1997-2004
Demirgüç-Kunt, Huizinga (2013)	Australia, 19 countries from Europe, Asia and Africa	1991-2208
Egly, Sun (2014)	USA	2001-2013
Elnahass et al. (2020)	15 countries from the Middle East, South Asia and North Africa	2010-2015
Elnahass et al. (2021)	116 countries	2019-2020
Fang et al. (2014)	11 countries from Central Europe	1997-2008
González-Rodríguez (2008)	27 countries	1995-1999
Haq et al. (2019)	Australia and Canada	1995-2011
He, Niu (2018)	USA	1990-2015
Hoang et al. (2019)	Australia	2000-2015
Jones et al. (2011)	USA	1988-2008
Kramaric et al. (2016)	Croatia	2002-2013
Laeven, Levine (2007)	43 countries	1998-2002
Liang et al. (2013)	12 countries from Western and Southern Europe	2000-2007
Premti et al. (2021)	28 EU countries	2013-2015
Saif-Alyousfi et al. (2021)	6 countries from The Gulf Cooperation Council	2000-2017
Shabir et al. (2023)	106 countries	2016-2021
Simoens, Vennet (2021)	16 countries from Europe and USA	2007-2017
Zhang et al. (2018)	China	2000-2015
Velasco (2022)	6 countries from West Europe, Australia, Canada, USA	2011-2017
Vu et al. (2023)	33 countries from Europe	2014-2022
Yildirim, Efthyvoulou (2018)	56 countries	2004-2013

Source: own study.

A narrative literature review was conducted, which is characterized by the absence of a rigorous methodological framework. The process of selecting articles began with identifying studies containing phrases such as "macroeconomic factors" and "market value" in databases like Science Direct, Emerald Insight, and Google Scholar. The review focused on academic articles published after the year 2000, while also including earlier key works where relevant. In the identified studies, particular attention was paid to the citations used—if the cited works matched the subject of analysis, they were also included in the literature review. It should be noted that this approach has certain limitations. A narrative literature review involves a high degree of subjectivity in selecting sources, which may have resulted in the omission of some relevant studies (Musiał, Rachuba, 2023).

3. The impact of key macroeconomic variables on the market value of banks

GDP and inflation are key macroeconomic indicators used to describe the overall condition of an economy. These variables are examined as potential determinants of firms' market value. Given their fundamental role, it is also worthwhile to highlight findings related to non-financial companies. The results of these studies are not conclusive.

In studies concerning non-financial companies, some authors identify a positive relationship between GDP growth and market value. This suggests that during periods of economic expansion, investors are more interested in acquiring new capital, which contributes to an increase in market value. A positive relationship is confirmed in cross-sectional studies covering multiple countries with varying levels of economic development (Chua et al., 2007; Bae et al., 2020; Fauver et al., 2017). Similar conclusions are drawn in empirical studies focusing on entities from South America (De la Hoz, Pombo, 2016) as well as from Poland (Hartwell, Malinowska, 2019).

Similar to non-financial companies, some studies indicate that GDP growth is associated with an increase in market value of banks. Periods of economic expansion are often related with rising demand for credit, which enhances the profitability of financial institutions. Higher profits, in turn, contribute to a higher market value of banks. The quality of loans issued during periods of economic expansion also plays a significant role in this process. In phases of GDP growth, banks tend to provide high quality loans, which leads to a reduction in credit risk. As a result, banks with lower credit risk are seen more positively by investors and usually have higher market values.

It is worth noting that a positive relationship has been found in countries with different levels of economic development. Such a result can be observed in the USA (Jones et al., 2011; Egly, Sun, 2014; He, Niu, 2018), China (Zhang et al., 2018) Tunisia (Alouane et al., 2022) Kuwait (Alyosef et al., 2019). A positive relationship is also demonstrated through cross-sectional analyses. Velasco (2022) confirms the positive impact of the recovery phase on the market value of banks from nine developed countries but this relationship does not show a high level of statistical significance. In European banks (Liang et al., 2013) and in a large sample of banks from 43 countries (Laven, Levine, 2007), the positive relationship appears to be much more statistically significant. Caprio et al. (2007) suggest that GDP growth contributes to an increase in the market value of banks in 44 countries. According to Alharbi et al. (2022), in Middle Eastern and South Asian countries, the positive effect of GDP on market value is evident in banks led by female CEOs.

Some studies also indicate a tendency for the market value of banks to decline during periods of economic expansion. Rapid economic growth increases competition in the banking sector, which results in lower lending margins. Lower profits from core operations are

associated with a decrease in market value (Saif-Alyousfi et al., 2021). A decline in market value during economic recovery is observed in both commercial and Islamic banks from Arab countries (AlKhouri, Arouri, 2019; Elnahass et al., 2020). A negative relationship is also found in banks from 27 countries (González-Rodríguez, 2008) and 34 countries (Demirgüç-Kunt, Huizinga, 2013), as well as in Australia and Canada (Haq et al., 2019), and in Australia alone (Hoang et al., 2019).

Another key macroeconomic factor associated with changes in the market value of both non-financial companies and banks is inflation. The measure of inflation used in the reviewed studies is the annual rate of change in the Consumer Price Index (CPI). Some authors report a negative relationship, indicating that company value decline during periods of rising prices. This relationship should be considered in connection with interest rates. When inflation exceeds target levels, central banks may respond by raising interest rates. Higher interest rates lead to increased capital costs for firms, which may discourage investment and, in turn, slow down economic growth. As a result, the market value of listed companies tends to fall. In studies of non-financial firms, a negative relationship between inflation and market value is confirmed by De-la-Hoz and Pombo (2016), and Faria and Mollick (2010).

The market value of banks also tends to decline under the influence of inflation. Fang et al. (2014) show that the negative relationship is strongest in post-communist Central European countries that have significantly liberalized their banking sectors. Liang et al. (2013) demonstrate that inflation has a negative impact on the market value of European banks expanding abroad by opening branches in other countries. Rising inflation also reduces bank value in Middle Eastern countries (AlKhouri, Arouri, 2019; Alyosef et al., 2019).

Some studies show an increased likelihood of higher market value during periods of rising inflation. Moderate inflation can signal economic growth, which tends to boost the stock market. In research on non-financial companies, Hartwell and Malinowska (2019) observed an increase in market value among Polish firms.

A positive link between inflation and the market value of banks is also found in several studies (Alouane et al., 2022; González-Rodríguez, 2008; Velasco et al., 2022). This result is not unexpected, as investment theories suggest that bank stocks can perform well during periods of rising inflation. This is because inflation is often followed by interest rate hikes, which can improve banks' earnings and boost their market value. However, some studies show that the level of inflation does not significantly impact bank valuation (De Jonghe, Vennet, 2008; Laeven, Levine, 2007; Hoang et al., 2019; Kramaric et al., 2016).

Interest rates are another fundamental macroeconomic variable with substantial implications for the financial sector. Due to their direct effect on banks' interest income, funding costs, and monetary transmission mechanisms, interest rates are examined as another key determinant of market value. They matter for bank stock valuation because banks' revenues and costs are closely tied to their level. Simoens and Vennet (2021) consider the central bank interest rate in the country where the bank is headquartered. Their findings show that an increase

in domestic interest rates is associated with a rise in the market value of European banks, while in the U.S., this relationship is not statistically significant.

Another interest rate-related factor examined in relation to bank valuation is government bond yields. Research indicates that the market value of EU banks is significantly affected by the spread between a country's 10-year government bond yield and the yield on 10-year German Bunds. Simoens and Vennet (2021) show that a wider spread significantly reduces the market value of financial firms. Long-term interest rates, based on yields from long-term government bonds or similar assets, also play a role. Studies show that the market value of EU banks increases during periods of rising long-term interest rates (De Jonghe, Vennet, 2008).

Among the key macroeconomic factors relevant to the market value of banks are public finance indicators and unemployment. Public finance factors relate to government spending and budget balance. Empirical studies show that investors tend to favor banks from countries with budget surpluses (Demirgüç-Kunt, Huizinga, 2013; Saif-Alyousfi et al., 2021), while rising government spending significantly reduces bank value (Demirgüç-Kunt, Huizinga, 2013). The link between unemployment and bank value is less frequently studied. Only He and Niu (2018) include this factor in their analysis, showing that the market value of bank holding companies is negatively related to the unemployment rate. This suggests that banks operating in stronger economies tend to have higher market value.

Another important aspect worth considering is the condition of the capital market, which may partially reflect the overall macroeconomic environment. Research shows that stock market indices also have a significant impact on the market value of banks. Market indices provide a summary measure of overall stock market performance and help predict trends in the entire market or specific sectors. When an index rises, it signals overall price increases and positive market sentiment. When it falls, it reflects worsening market conditions. Studies show a positive relationship. For European banks, market value is positively linked to the Stoxx Europe 600 index (Simoens, Vennet, 2021). A similar positive relationship is observed when national stock indices are considered (De Jonghe, Vennet, 2008). In the United States, the S&P 500 index is also found to positively influence the market value of banks (Jones et al., 2011; Simoens, Vennet, 2021).

Energy plays a key role in stimulating national economic growth. Oil and natural gas are important components in the production process, so price volatility in these resources affects the real economy, and consequently, the market value of banks. Saif-Alyousfi et al. (2021) conduct such an analysis on a sample of banks from oil- and gas-exporting countries. The authors use five indicators to measure price shocks. The results, based on commercial and Islamic banks, suggest that oil and gas price shocks have a direct impact on the market value of banks. An increase (decrease) in oil and gas prices raises (lowers) the market value of banks. These findings are stable regardless of the definitions of price shocks used.

4. The impact of institutional and regulatory factors on the market value of banks

Institutional reforms are part of the broader category of macroeconomic factors influencing bank market value. Fang et al. (2014) conducted an extensive study on how such reforms affect the market value of banks in Central European countries. Their analysis is focused on reforms in the banking sector, capital markets, and legal systems, particularly regarding collateral and bankruptcy regulations.

The level of banking reform implementation is assessed using an index developed by the European Bank for Reconstruction and Development (EBRD). This index measures progress in areas such as the creation of a two-tier banking system, increased independence of central banks in setting interest rates, development of banking supervision and prudential regulation frameworks, and alignment with Basel Committee principles. A higher index score reflects more advanced interest rate liberalization, greater freedom in credit allocation, improved supervision standards, increased lending to private firms, and a stronger presence of private banks in the sector.

The EBRD also provided an index to assess capital market reforms. This measure evaluates whether a country has established stock exchanges and regulatory agencies, including market makers. The index also captures whether independent share registries have been established and whether non-bank financial institutions, such as insurance companies, operate in the market. It also assesses the legal framework for issuing and trading securities. The analysis includes the volume of securities issued by private companies and the degree of protection for minority shareholders. A higher index score indicates that a country's regulations are moving closer to the standards seen in developed economies.

The third index used by Fang et al. (2014) assesses the progress of legal reforms in the areas of collateral and bankruptcy regulations. Collateral laws define the types and extent of security that lenders can require, while bankruptcy laws govern how creditors collectively recover claims from insolvent debtors.

The results show that after implementing reforms in bankruptcy and collateral laws, banks significantly increase their lending activity, which leads to higher market value. Fang et al. (2014) also find that greater progress in banking sector reforms raises bank market value by improving their financial stability. In contrast, the development of capital markets has a negative effect on bank valuation. According to the authors, this is because, in such conditions, more firms start seeking financing through stock markets instead of relying on bank loans.

Further studies examining the impact of regulation on bank market value include those by González-Rodríguez (2008) and Liang et al. (2013). González-Rodríguez (2008) focuses on regulatory restrictions related to banks' activities. The measure used in the study assesses the

level of freedom banks have in operating in securities, insurance, and real estate markets. A higher score indicates stricter regulations, while a lower score reflects fewer limitations. The results suggest no statistically significant relationship between this index and bank market value. Similarly, Liang et al. (2013), who focus on capital markets, find no significant link between regulatory restrictions on bank activity in these markets and their market value.

Researchers also consider the quality of the institutional and legal environment when analyzing banks, using the Index of Economic Freedom developed by the Heritage Foundation and *The Wall Street Journal*. This index assesses the level of economic freedom in 10 areas, including banking and finance, government intervention, taxation, wages and prices, trade policy, monetary policy, property rights, capital flows and foreign investment, legal regulations, and the shadow economy. González-Rodríguez (2008) focuses on the property rights sub-index, where a higher score indicates weaker government protection and enforcement of private property rights. The results show a negative impact on bank market value—suggesting that the weaker the property rights protection in a country, the lower the market value of its banks.

De Jonghe and Vennet (2008) also use the Index of Economic Freedom in their analysis, focusing not only on property rights protection but also on two additional components: business freedom and banking freedom. The business freedom index is based on measures of how easy or difficult it is to start, operate, and close a business. The banking freedom index assesses the level of regulation in the banking sector, including the degree of freedom for domestic and foreign banks and the role of state-owned banks. It also considers whether the government influences credit allocation. The results show that only the business freedom index has a significant negative effect on bank market value. This relationship may be explained by the fact that new firms often secure loans at lower margins, which reduces bank profits and, in turn, their market value.

The literature also examines the relationship between the introduction of specific legal acts and the market value of banks. Premti et al. (2021) focus on the Fourth Anti-Money Laundering Directive (4AMLD), introduced by the European Commission on May 20, 2015. Their study analyzes stock price reactions across eight key events, starting with the first announcement (February 5, 2013) and ending with the directive's formal implementation (June 26, 2015). The authors investigate whether the benefits of introducing the directive are greater in countries with higher levels of corruption.

Premti et al. (2021) use the Corruption Perceptions Index, which ranks countries based on how experts and the public view corruption in the public sector. They also analyze the quality of governance using the World Bank's Worldwide Governance Indicators, which evaluate executive functioning across six areas: voice and accountability, political stability, government effectiveness, regulatory quality, rule of law, and control of corruption. Additionally, the study considers a country's level of wealth, measured by GDP per capita, as a potential factor influencing the relationship between the implementation of 4AMLD and bank market value.

The findings show that adopting the directive has a positive effect on banks' market value. This positive relationship is especially strong for banks in countries with high levels of corruption, suggesting that where money laundering is more common, the directive brings greater credibility and value to the banking sector. Banks in wealthier countries also experience a rise in market value. In countries with strong governance scores, the directive's impact is less pronounced, likely because these countries already have effective anti-money laundering systems in place.

The Worldwide Governance Indicators used in Premti et al. (2021) are also applied in studies by Alharbi et al. (2022), Elnahass et al. (2020), and Yildirim and Efthyvoulou (2018). Elnahass et al. (2020) find that higher governance scores are linked to increased market value, suggesting that shareholders are more willing to invest in countries with better governance. Yildirim and Efthyvoulou (2018) note that this positive effect appears only in developing countries, while in developed economies it is no longer statistically significant. Alharbi et al. (2022) report that higher governance quality does not have a significant impact on the market value of banks in the countries they studied.

The market value of banks is also studied in relation to the legal protection of minority shareholders. Research shows that the level of investor protection in a given country is an important factor contributing to the development of financial markets. In countries where minority shareholders are well protected, they are more willing to provide funding to companies. This is because they are confident they won't be expropriated by majority owners (La Porta et al., 2002). Shareholder rights influence not only the growth of financial markets but also the market value of individual firms. Caprio et al. (2007) assess the relationship between minority shareholder rights and bank market value using a composite index ranging from zero to six. Higher values of the index indicate stronger rights for bank shareholders. Their findings show that better protection of minority owners encourages investment, which in turn increases the market value of banks.

5. Market value of banks in times of economic uncertainty and global disruptions

Uncertainty related to economic policy and external shocks has become an increasingly important area of research in the context of financial markets. These factors can significantly influence investor sentiment and the valuation of companies, including banks. Some studies explore the relationship between Economic Policy Uncertainty (EPU) and company market value. The EPU index reflects the frequency of newspaper articles that mention words like "uncertainty" in an economic context. Research on non-financial firms shows that in some countries, an increase in EPU is associated with a significant drop in firm value—both in the

short term (Chen et al., 2017; Jory et al., 2020) and over the longer term (Yang et al., 2019). In the banking sector, the impact of policy uncertainty on market value tends to be indirect. A higher EPU index slows down credit growth, which in turn lowers the market value of banks (He, Niu, 2018).

The turbulent events of 2020-2023 provide an important context for research on bank market value. Vu et al. (2023) analyze changes in the market value of European banks in response to increased risks related to Brexit, the Covid-19 pandemic, and Russia's invasion of Ukraine. Their findings show a significant decline in market value during these events, especially among small and young banks. Vu et al. (2023) also find that the negative impact of such shocks is less pronounced in banks with high capital adequacy ratios.

The impact of the Covid-19 pandemic on the market value of banks is analyzed also by Elnahass et al. (2021). The authors examine the years 2019-2020 and show that in the first two quarters of 2020, banks had lower market value compared to the other quarters. Similar conclusions are drawn by Shabir et al. (2023), who also use quarterly data. The authors analyze the years 2016-2021 and define the pandemic period as the first three quarters of 2021.

6. Conclusions

The literature review identified a wide range of macroeconomic factors examined in relation to the market value of banks. These factors can be classified into three groups. The first group comprises fundamental indicators commonly used to characterize the condition of an economy, including GDP, inflation, interest rates, the government budget balance, the unemployment rate, stock market performance, and energy prices. The second group includes institutional and regulatory factors, such as reforms of the banking and capital markets, indicators reflecting the quality of the institutional environment, and the level of minority shareholder protection. The third group includes Economic Policy Uncertainty index and external shocks.

For many variables, the findings remain inconclusive. Differences in results across countries and time periods suggest that the relationship between macroeconomic conditions and the market value of banks is complex and potentially non-linear. This lack of consistency highlights the need for further in-depth research into where these differences may stem from. The conducted literature review may serve as a starting point for designing future research. It is worth emphasizing that, compared to non-financial firms, studies focusing on the macroeconomic environment and the market value of banks still constitute a relatively small part of the literature. This highlights the need to expand research in this area.

From a theoretical perspective, several frameworks can help explain the observed relationships between macroeconomic variables and the market value of banks. Tobin's Q theory (Tobin, 1969) suggests that the ratio between market value and the

replacement cost of assets can reflect investment opportunities and firm efficiency, while macroeconomic conditions may influence this ratio by altering expected profitability or the cost of capital. Signaling theory (Connelly et al., 2011) highlights how banks' market value may reflect investors' interpretations of economic signals such as inflation or changes in interest rates as indicators of future performance. Market efficiency theory (Fama, 1970), in turn, assumes that all available information, including macroeconomic data, is quickly reflected in stock prices, although mixed empirical results suggest that inefficiencies may exist across different countries and banking systems. Integrating these theoretical approaches may provide a coherent framework for interpreting the empirical inconsistencies observed in the literature.

A critical review of the empirical literature reveals a substantial variation in the methodological rigor and robustness of studies investigating the relationship between macroeconomic conditions and the market value of banks. The most advanced approaches include dynamic panel estimators, such as system GMM (Alkhouri, Arouri, 2019; Yildirim, Efthyvoulou, 2018), or three-stage least squares (3SLS) and simultaneous equation systems (Alharbi et al., 2022; González-Rodríguez, 2008), which are particularly well-suited for addressing endogeneity and reverse causality. These techniques enhance internal validity and allow for more reliable inferences about the causal impact of macro-level determinants on bank valuation. By contrast, several studies rely on static panel models or OLS regressions (Alyousef et al., 2019; Liang et al., 2013), which may suffer from omitted variable bias and fail to control for the persistence of firm-level performance.

Another notable methodological innovation is the application of stochastic frontier analysis by De Jonghe and Vander Vennet (2008), who construct a noise-adjusted Tobin's Q as a more accurate proxy for long-term franchise value. Similarly, some studies incorporate event-study designs (Premti et al., 2021) or difference-in-differences frameworks (Fang et al., 2014), which enhance causal identification in policy-relevant contexts but may lack external generalizability. In sum, the empirical evidence is heterogeneous not only in terms of findings, but also in the strength and credibility of inference. For this reason, greater weight should be given to studies that adopt dynamic or multi-equation models with appropriate instruments, robust diagnostics, and panel structures covering a wide range of countries and macroeconomic conditions.

A better understanding of the relationship between macroeconomic conditions and the market value of banks is especially important for investors and financial analysts, as it can help them better assess the risks and opportunities of investing in the banking sector under different economic conditions. It is also useful for bank managers and decision-makers, who can use this knowledge to plan strategies that support or improve the bank's market value when the economic environment changes.

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References

1. Alharbi, R., Elnahass, M., McLaren, J. (2022). Women directors and market valuation: What are the "Wonder Woman" attributes in banking? *Journal of International Financial Markets, Institutions and Money*, *Vol. 80*, 101611, doi: 10.1016/j.intfin.2022.101611
2. AlKhouri, R., Arouri, H. (2019). The effect of diversification on risk and return in banking sector: Evidence from the Gulf Cooperation Council countries. *International Journal of Managerial Finance*, *Vol. 15, No. 1*, pp. 100-128. doi: 10.1108/IJMF-01-2018-0024
3. Alouane, N., Kahloul, I., Grira, J. (2022). The trilogy of ownership, income diversification, and performance nexus: empirical evidence from Tunisian banks. *Finance Research Letters*, *Vol. 45*, 102180. doi: 10.1016/j.frl.2021.102180
4. Alyousef, H.Y., Saffouri, R.O., Alqassar, A.F. (2019). Bank-Specific and Macroeconomic Determinants of Bank Profitability: Evidence from Kuwaiti Banks. *International Research Journal of Finance and Economics*, *Vol. 176*, pp. 167-81.
5. Bae, K. H., Ding, Y., Wang, X. (2020). Relative industry valuation and cross-border listing. *Journal of Banking and Finance*, *Vol. 119*, 105899. doi: 10.1016/j.jbankfin.2020.105899
6. Caprio, G., Laeven, L., Levine, R. (2007). Governance and bank valuation. *Journal of Financial Intermediation*, *Vol. 16, Iss. 4*, pp. 584-617. doi: 10.1016/j.jfi.2006.10.003
7. Chua, C.T., Eun, C.S., Lai, S. (2007). Corporate valuation around the world: The effects of governance, growth, and openness. *Journal of Banking and Finance*, *Vol. 31, Iss. 1*, pp. 35-56. doi: 10.1016/j.jbankfin.2006.02.002
8. Connelly, B.L., Certo, S.T., Ireland, R.D., Reutzel, C.R. (2011). Signaling theory: A review and assessment. *Journal of Management*, *Vol. 37, Iss. 1*, pp. 39-67. doi: 10.1177/01492063103884
9. De Jonghe, O., Vander Vennet, R. (2008). Competition versus efficiency: What drives franchise values in European banking? *Journal of Banking and Finance*, *Vol. 32, Iss. 9*, pp. 1820-1835. doi: 10.1016/j.jbankfin.2007.12.009
10. De-la-Hoz, M.C., Pombo, C. (2016). Institutional investor heterogeneity and firm valuation: Evidence from Latin America. *Emerging Markets Review*, *Vol. 26*, pp. 197-221. doi: 10.1016/j.jbankfin.2006.02.002

11. Demirgüç-Kunt, A., Huizinga, H. (2013). Are banks too big to fail or too big to save? International evidence from equity prices and CDS spreads. *Journal of Banking and Finance*, *Vol. 37, Iss. 3*, pp. 875-894. doi: 10.1016/j.jbankfin.2012.10.010
12. Egly, P.V., Sun, J. (2014). Trading income and bank charter value during the financial crisis: Does derivatives dealer designation matter? *The Quarterly Review of Economics and Finance*, *Vol. 54, Iss. 3*, pp. 355-370. doi: 10.1016/j.qref.2014.04.001
13. Elnahass, M., Omoteso, K., Salama, A., Trinh, V.Q. (2020). Differential market valuations of board busyness across alternative banking models. *Review of Quantitative Finance and Accounting*, *Vol. 55,* pp. 201-238. doi: 10.1007/s11156-019-00841-4
14. Elnahass, M., Trinh, V.Q., Li, T. (2021). Global banking stability in the shadow of Covid-19 outbreak. *Journal of International Financial Markets, Institutions and Money*, *Vol. 72*, 101322. doi: 10.1016/j.intfin.2021.101322
15. Fama, E.F. (1970). Efficient Capital Markets: A Review of Theory and Empirical Work. *The Journal of Finance*, *Vol. 25, No. 2*, pp. 383-417. doi: 10.2307/2325486
16. Fang, Y., Hasan, I., Marton, K., Waisman, M. (2014). Bank valuation in new EU member countries. *Economic Systems*, *Vol. 38, Iss. 1*, pp. 55-72. doi: 10.1016/j.ecosys.2013.07.002
17. Faria, J.R., Mollick, A.V., Sachsida, A., Wang, L. (2012). Do central banks affect Tobin's q? *International Review of Economics and Finance*, *Vol. 22, Iss. 1*, pp. 1-10. doi: 10.1016/j.iref.2011.08.003
18. Fauver, L., Hung, M., Li, X., Taboada, A.G. (2017). Board reforms and firm value: Worldwide evidence. *Journal of Financial Economics*, *Vol. 125, Iss. 1*, pp. 120-142. doi: 10.1016/j.jfineco.2017.04.010
19. González-Rodríguez, F. (2008). The relationship between charter value and bank market concentration: the influence of regulations and institutions. *Applied Financial Economics*, *Vol. 18, Iss. 2*, pp. 153-172. doi: doi.org/10.1080/09603100601083215
20. Haq, M., Avkiran, N.K., Tarazi, A. (2019). Does market discipline impact bank charter value? The case for Australia and Canada. *Accounting and Finance*, *Vol. 59, Iss. 1*, pp. 253-276. doi: 10.1111/acfi.12244
21. Hartwell, C.A., Malinowska, A.P. (2019). Informal institutions and firm valuation. *Emerging Markets Review*, *Vol. 40*, 100603. doi: 10.1016/j.ememar.2019.03.001
22. He, Z., Niu, J. (2018). The effect of economic policy uncertainty on bank valuations. *Applied Economics Letters*, *Vol. 25, Iss. 5*, pp. 345-347. doi: 10.1080/13504851.2017.1321832
23. Hoang, V.H., Hoang, N.T., Yarram, S.R. (2019). Efficiency and shareholder value in Australian banking. *Economic Record*, *Vol. 96, Iss. 312*, pp. 40-64. doi: 10.1111/1475-4932.12508
24. Jones, J.S., Miller, S.A., Yeager, T.J. (2011). Charter value, Tobin's Q and bank risk during the subprime financial crisis. *Journal of Economics and Business*, *Vol. 63, Iss. 5*, pp. 372-391. doi: 10.1016/j.jeconbus.2010.10.003

25. Kramaric, T.P., Pervan, M. (2016). Does board structure affect the performance of Croatian banks? *Journal of Financial Studies and Research*, pp. 1-10. doi: 10.5171/2016.158535
26. La Porta, R., Lopez-de-Silanes, F., Shleifer, A., Vishny, R. (2002). Investor protection and corporate valuation. *The Journal of Finance*, *Vol. 57, Iss. 3*, pp. 1147-1170. doi: 10.1016/j.ibusrev.2012.07.003
27. Laeven, L., Levine, R. (2007). Is there a diversification discount in financial conglomerates? *Journal of Financial Economics*, *Vol. 85, Iss. 2*, pp. 331-367. doi: 10.1016/j.jfineco. 2005.06.001
28. Liang, H.Y., Ching, Y.P., Chan, K.C. (2013). Enhancing bank performance through branches or representative offices? Evidence from European banks. *International Business Review*, *Vol. 22, Iss. 3*, pp. 495-508. doi: 10.1016/j.ibusrev.2012.07.003
29. Musiał, M., Rachuba, J. (2023). Nierówności płci w dostępie do kredytu. *Przegląd Organizacji*, *No. 3*, pp. 240-247. doi: 10.33141/po.2023.03.25
30. Premti, A., Jafarinejad, M., Balani, H. (2021). The impact of the Fourth Anti-Money Laundering Directive on the valuation of EU banks. *Research in International Business and Finance*, *Vol. 57*, 101397. doi: 10.1016/j.ribaf.2021.101397
31. Saif-Alyousfi, A.Y., Saha, A., Md-Rus, R., Taufil-Mohd, K. N. (2021). Do oil and gas price shocks have an impact on bank performance? *Journal of Commodity Markets*, *Vol. 22*, 100147. doi: 10.1016/j.jcomm.2020.100147
32. Shabir, M., Jiang, P., Wang, W., Işık, Ö. (2023). COVID-19 pandemic impact on banking sector: A cross-country analysis. *Journal of Multinational Financial Management*, *Vol. 67*, 100784. doi: 10.1016/j.mulfin.2023.100784
33. Simoens, M., Vander Vennet, R. (2021). Bank performance in Europe and the US: A divergence in market-to-book ratios. *Finance Research Letters*, *Vol. 40*, 101672. doi: 10.1016/j.frl.2020.101672
34. Tobin, J. (1969). A general equilibrium approach to monetary theory. *Journal of Money, Credit and Banking*, *Vol. 1, Iss. 1*, pp. 15-29. doi: 10.2307/1991374
35. Velasco, P. (2022). Is bank diversification a linking channel between regulatory capital and bank value? *The British Accounting Review*, *Vol. 54, Iss. 4*, 101070. doi: 10.1016/j.bar.2021.101070
36. Vu, P.T.T., Huynh, N., Phan, H., Hoang, H. (2023). Financial earthquakes and aftershocks: From Brexit to Russia-Ukraine conflict and the stability of European banks. *Journal of International Financial Markets, Institutions and Money*, *Vol. 88*, 101830. doi: 10.1016/j.intfin.2023.101830
37. Yildirim, C., Efthyvoulou, G. (2018). Bank value and geographic diversification: regional vs global. *Journal of Financial Stability*, *Vol. 36*, pp. 225-245. doi: 10.1016/j.jfs.2018.04.003
38. Zhang, J., Jiang, H. (2018). Capital regulatory pressure, charter value and bank risk-taking: empirical evidence for China. *Journal of Financial Regulation and Compliance*, *Vol. 26, No. 1*, pp. 170-186. doi: 10.1108/JFRC-01-2017-0002

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CSR IN HIGHER EDUCATION: THE CASE OF THE UNIVERSITY OF SZCZECIN

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Purpose: This paper aims to examine how the University of Szczecin addresses Corporate Social Responsibility (CSR) within its institutional framework. Employing a case study approach, the research investigates the university's strategies and initiatives that reflect its commitment to ethical practices, sustainability, and community engagement. By analyzing these efforts, the study seeks to understand the role of CSR in shaping the university's operations and its impact on stakeholders.
Design/methodology/approach: This paper employs a qualitative case study approach focusing on the University of Szczecin. Data were collected through content analysis of publicly available materials, including strategic documents, CSR reports, and information published on the university's official websites. This study employed a qualitative content analysis approach grounded in thematic coding.
Findings: The University of Szczecin has undertaken various Corporate Social Responsibility (CSR) initiatives, including the incorporation of CSR topics into academic programs, the establishment of ethical practice and others. However, the study identifies that the university's communication of these CSR activities is limited, with insufficient visibility on official platforms. Additionally, the absence of formal CSR reporting mechanisms further obscures the extent and impact of these initiatives, making it challenging to assess their effectiveness and areas for improvement.
Research limitations/implications: The research is limited to a single institution, which may affect the generalizability of the findings.
Practical implications: The findings offer practical insights for university policymakers aiming to integrate CSR into higher education institutions. By highlighting effective strategies and identifying areas needing attention, the study provides a roadmap for enhancing CSR practices.
Social implications: The integration of CSR in higher education has the potential to foster a culture of social responsibility among students and staff, leading to positive societal impacts. The University of Szczecin's initiatives serve as a model for how academic institutions can contribute to sustainable development and community well-being.
Originality/value: This study offers valuable insights into the practical application of Corporate Social Responsibility principles within a Polish higher education institution. By focusing on the University of Szczecin, it provides a detailed examination of how CSR initiatives are implemented in the academic context, highlighting both achievements and areas needing improvement.

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Category of the paper: Case study.

1. Introduction

Corporate Social Responsibility (CSR) has evolved from a concept primarily associated with the business sector to a multifaceted framework embraced by higher education institutions. University Social Responsibility (USR) represents a strategic commitment by higher education institutions to engage in ethical practices and actively consider the interests of a broad range of stakeholders, including students, staff, local communities, and the environment. USR focuses on the university's role in promoting social equity, environmental stewardship, and community well-being. By integrating these principles into their core missions of education, research, and public service, universities act as catalysts for positive societal change, shaping not only academic outcomes but also contributing to the holistic development of the communities they serve. The main objective of the article is to explore how the University of Szczecin addresses CSR within its institutional framework, focusing on strategies and initiatives that promote ethics, sustainability, and community engagement.

A case study of the University of Szczecin will provide a better understanding of the mechanisms of implementing Corporate Social Responsibility in academic institutions and its potential in supporting sustainable development and stakeholder engagement. The research topic was implemented using the critical evaluation method, including literature analysis, reports, strategic documents, and information published on the university's official websites.

It is important to clarify that this study employed a qualitative content analysis approach grounded in thematic coding. The analysis was conducted in several stages. First, relevant CSR-related initiatives were identified through a systematic review of official university documents, including strategic plans, policy statements, reports. Next, initiatives were categorized according to two core CSR dimensions: activities directed towards external stakeholders and activities directed towards internal stakeholders. Coding was performed manually using predefined thematic categories derived from both the literature and institutional priorities. To ensure data reliability and minimize researcher bias, a triangulation strategy was applied by cross-referencing data from multiple independent sources.

2. CSR in the Academic Context

Corporate social responsibility constitutes a complex and multidimensional construct, a characteristic that largely stems from its inherently interdisciplinary nature. As a result, CSR is defined and interpreted in diverse ways across academic literature, international policy documents, and institutional frameworks. The multitude of definitions and thematic approaches to CSR not only reflects the richness of the discourse but also underscores the growing significance and popularity of the concept within the field of management studies. In a broad academic context, CSR encompasses a wide array of interrelated concepts such as corporate responsibility, corporate accountability, business ethics, corporate citizenship, responsible entrepreneurship, and sustainable development, including environmental stewardship (Lu et al., 2019).

The concept of the "social responsibility of the university" gained broader recognition in the 1980s, largely due to the influential work of D. Bok in his book Beyond the Ivory Tower. Social Responsibility of the Modern Universities (Bok, 1982). In this publication, Bok emphasized the fundamental values that underpin academic institutions, and he critically examined the ethical and social challenges confronting modern universities. Importantly, he went beyond diagnosis and proposed practical solutions, thus offering one of the first comprehensive analyses of the university's role and obligations toward society. His work laid the foundation for further discussions on how higher education institutions should engage with societal issues in an ethically responsible manner.

As social responsibility of organizations is concerned with economic, legal, altruistic, and moral responsibilities, in the same sense institutions of higher education are required to exceed their fundamental responsibility of developing students, creating research and community outreach, and adjust these activities to the concept of USR (Ali et al., 2020).

In the evolving discourse on the role of higher education institutions in modern society, it becomes increasingly evident that their mission extends far beyond traditional teaching and research activities. Universities are expected to serve as active agents of societal progress, contributing to sustainable development and social well-being through their core functions and institutional behavior. This broader perspective is reflected in the following definition from the Oxford Research Encyclopedia (Vargas, 2023) “University social responsibility is an approach that goes beyond understanding the university as a transmitter of content and the training of future professionals. As an institution, it has a social mission: to positively transform and promote the social, economic and environmental development. It draws on the morality, ethics and responsibility of the entire university community to promote a culture and awareness of evaluation and self-assessment”. This conceptualization underscores the comprehensive and integrative nature of USR, positioning it as a shared responsibility that mobilizes all stakeholders within the university. It also highlights the importance of ethical commitment and reflective practices as foundations for institutional accountability and long-term societal impact.

According to Reiser (2007), the concept of University Social Responsibility refers to the ethical commitment of the entire academic community—including students, academic staff, and administrative personnel—to managing the educational, research-related, labor, and environmental impacts generated by the institution. This responsibility is exercised through active and reciprocal engagement with society, with the overarching aim of fostering sustainable human development.

USR is regarded as an innovative and strategic management approach within the context of higher education institutions (Valencia-Arias et al., 2024). K. Leja (2008) defines a socially responsible university as one that actively responds to societal needs by fostering close cooperation with the business sector and local government, while also ensuring that graduates are equipped to serve as knowledge workers who contribute to the development of the socio-economic environment.

The social responsibility of a higher education institution is a commitment of the university institution to develop initiatives that promote its relationship with the different social groups of society (Meseguer-Sánchez et al., 2020). Moreover, a socially responsible university is a higher education institution serving its environment whose responsibility towards the society is related to preparing graduates to perform the function of employees of knowledge and to building close relations with the economic practice and local authorities (Szelągowska-Rudzka et al., 2018, p. 88). Social responsibility enables universities to comprehensively understand the context in which they operate and to recognize the broader societal impact of their activities, extending beyond the immediate region in which they are situated (Brown et al., 2015).

The concept of University Social Responsibility encompasses ethical, political, environmental, social, and educational dimensions—domains in which universities exert a measurable impact, thereby fostering human development processes within their respective regions (Espinoza Santeli et al., 2018). In this way, USR positions universities as key agents of regional sustainable development.

The strategy of social responsibility should be closely aligned with the university's overall strategic framework and serve as a response to external challenges, including social, economic, and environmental changes. From this perspective, social responsibility becomes an inherent element of the university's identity — embedded in its vision, mission, and core values, and further reflected in strategic objectives, institutional policies, dedicated programs, and operational procedures (Bukowska-Piestrzyńska et al., 2025). This comprehensive integration of social responsibility into the university's strategic and operational structure highlights its long-term commitment to societal engagement. It suggests that social responsibility is not an isolated initiative, but rather a guiding principle that permeates institutional culture and decision-making processes.

It is worth emphasizing that the concept of University Social Responsibility is not merely a set of operational actions, but above all a philosophy that should be embraced by every higher education institution as an ethical framework for its development and for active engagement

with both regional and global communities (Kieżel et al., 2021). USR assumes that the university does not operate in isolation but plays a vital role in shaping the quality of its surrounding environment, contributing to responsible, sustainable, and inclusive social development.

The Ministry of Education and Science in Poland encourages higher education institutions to join the Declaration of Social Responsibility of Universities, which represents a voluntary commitment to promoting sustainable development and social responsibility in academic curricula, as well as in university management and organizational practices. By signing the Declaration, universities demonstrate their proactive stance on integrating these values into both education and governance (The Ministry of Education and Science, 2025). Among the signatories is the University of Szczecin, along with 76 other institutions from across Poland. In total, 160 universities have signed the Declaration of Social Responsibility of Universities across three rounds of endorsement in 2017, 2019, and 2022.

3. Selected CSR initiatives at the University

The University of Szczecin, established in 1984, is the largest public higher education institution in the West Pomeranian region of Poland. It plays a vital role in the academic, cultural, and social life of the city and region. The mission of the University of Szczecin is to educate and shape young people in the spirit of humanistic, democratic, and pro-social values. The values that guide the University's activities are integrity, openness, commitment, and responsibility. The institution emphasizes values such as academic freedom, sustainable development, and social engagement, which are reflected in its strategic documents and various initiatives. As a public university, it is committed not only to education and research, but also to contributing to the well-being of its stakeholders through socially responsible practices.

Socially responsible practices are directed toward both internal and external stakeholders. Internal stakeholders of a university include academic and research staff, administrative employees, students, and the university's leadership, such as the rector, deans, directors, and department heads. External stakeholders, on the other hand, encompass graduates, employers and other businesses, the media, the local community, and various organizations with which the university cooperates. These groups play a significant role in shaping and evaluating the university's social responsibility efforts.

The University of Szczecin's development strategy for 2019-2028 articulates a comprehensive approach to integrating CSR into its institutional framework. The strategy emphasizes the university's commitment to sustainable development, ethical governance, and active engagement with both internal and external stakeholders. Key objectives include fostering social inclusion, promoting environmental sustainability, and enhancing economic

responsibility through education, research, and community outreach. These strategic directions align with global standards and reflect the university's dedication to embedding CSR principles across all facets of its operations (University of Szczecin, 2025a).

Among the noteworthy examples of good CSR practices at the University of Szczecin is the establishment of dedicated institutional roles and committees specifically focused on the promotion and coordination of corporate social responsibility. At the University of Szczecin, there is a position of the Rector's Plenipotentiary for Corporate Social Responsibility. The Rector's Plenipotentiary for Corporate Social Responsibility at the University of Szczecin is responsible for promoting CSR principles, sustainable development, and green economy among all university stakeholders. This includes raising awareness of the university's ecological, cultural, and social responsibilities, organizing educational and environmental initiatives, and monitoring compliance with CSR standards.

In 2024, the University of Szczecin established the Rector's Committee for University Social Responsibility, providing further evidence of the institution's commitment to integrating social responsibility into its strategic and operational framework. The Committee is responsible for promoting and overseeing university social responsibility, integrating sustainability and ethics into academic activities, engaging stakeholders, and supporting the university's social and environmental transformation.

In order to strengthen its commitment to equality and non-discrimination, the University of Szczecin has introduced dedicated roles of Equality Officers for both employees and for students and doctoral candidates. Appointed by the Rector for the duration of their term, these officers are responsible for promoting equal treatment and addressing issues related to discrimination and harassment within the academic community. Their duties include conducting proceedings, organizing awareness-raising initiatives, supporting the implementation of anti-discrimination policies, and acting as confidential contacts for those affected. Additionally, they analyze structural challenges, mediate conflicts, and provide recommendations aimed at improving institutional practices in the area of equal opportunity and fairness.

As part of a broader institutional commitment to social responsibility, equality, and inclusion, the University of Szczecin has also established the Support Office for Persons with Disabilities. Its activities were initiated in 2007 by the Rector of the University. The creation of this unit reflects the university's strategic approach to ensuring equal opportunities in education and fostering an inclusive academic environment.

The primary mission of the office is to provide tailored support to students with disabilities, enabling them to fully participate in the educational process. At the same time, it offers practical and substantive assistance to academic and administrative staff working with students who hold disability certificates.

The establishment of these positions reflects the University of Szczecin's strategic commitment to corporate social responsibility, sustainable development, and the principles of equality and inclusion. The initiatives undertaken by the appointed officers aim to integrate these values into the university's mission and daily operations, while also fostering constructive relationships with both internal and external stakeholders.

Another important instrument of socially responsible policy at the university is the implementation of various codes of conduct addressed to both staff and students. The norms and principles outlined in these documents serve as practical guidelines for appropriate behavior in specific situations, helping individuals distinguish between acceptable and unacceptable actions. At the University of Szczecin, such documents include the Code of Ethics for Academic Teachers, the Student Code of Ethics, and the Good Practices at the University of Szczecin, which is specifically addressed to students. These codes reflect the university's commitment to fostering a culture of integrity, responsibility, and mutual respect within the academic community.

In accordance with this Code, academic teachers are expected to carry out their research, teaching, and public engagement with integrity, honesty, and responsibility. They are required to uphold ethical principles related to respect for life, human and animal welfare, environmental protection, personal autonomy, intellectual honesty, and the fulfillment of professional commitments. These standards encompass both general moral conduct and professional academic ethics. It also clearly prohibits any form of discrimination based on gender, skin color, ethnicity, nationality, religion, belief system, disability, age, or sexual orientation, underscoring the University's commitment to equality, inclusivity, and respect within the academic community (University of Szczecin, 2025b).

Based on the ethical principles set out in the Student Code of Ethics at the University of Szczecin, a number of values align closely with the principles of corporate social responsibility, particularly in the domains of ethics, equality, and respect for human dignity. According to the Code, students are expected to seek truth through the acquisition of knowledge and self-improvement, and to exercise freedom of speech with due regard for facts and standards of fair argumentation. Importantly, they are required to respect differing viewpoints and individuals expressing them, while avoiding all forms of discrimination. This provision directly reinforces CSR principles related to diversity, equity, and inclusion (University of Szczecin, 2025c).

What is more, students are encouraged to uphold integrity in their academic work by respecting intellectual property and adhering to ethical standards when using artificial intelligence. These aspects resonate with the broader CSR agenda of responsible use of technology and knowledge sharing.

Additionally, students are expected to care for the well-being of the academic community, foster interpersonal relations with respect and courtesy, and avoid conduct that violates social norms.

Another socially responsible initiative undertaken by the University of Szczecin, targeting a broad spectrum of stakeholders—including businesses, the media, local authorities, and the wider academic community—is the annual "Równa Firma" (Equal Company) competition. The primary objective of this initiative is to recognize socially responsible organizations within the region that demonstrate voluntary and proactive engagement in practices that go beyond legal requirements, particularly in their commitment to employees, contractors, local communities, and environmental sustainability.

It is important to emphasize that the exemplary practices highlighted through this competition have served as the foundation for the development of CSR good practice guides. These guides offer valuable insights for other organizations, showcasing which types of socially responsible activities are appreciated by the surrounding community and should be rewarded not only through public recognition, but also by consumers' purchasing decisions. In this sense, the initiative serves as a mechanism for shaping consumer awareness and encouraging ethical market behavior.

Moreover, the "Równa Firma" competition exemplifies effective university engagement with the socio-economic environment. It facilitates collaborative projects involving academic staff and students, integrating CSR-related case studies into educational processes and providing a basis for bachelor's and master's theses. In this context, corporate social responsibility becomes a strategic tool for building an organization's image—not only in the marketplace but also in the labor market and academic environment—through internships, student placements, recruitment of future employees, and joint research activities.

The University of Szczecin engages in multifaceted cooperation with its socio-economic environment. One of the key initiatives in this regard is the establishment of Employer Councils, whose primary objective is to align educational programs with the needs and expectations of the regional labor market. The University organizes open meetings between students, academic staff, and invited entrepreneurs, as well as representatives of local business support institutions. Encounters with practitioners on campus constitute a crucial component of the educational process, as they facilitate the exchange of practical knowledge and professional experiences. Such interactions also contribute significantly to the development of students' interpersonal skills. Moreover, academic staff members actively participate in various initiatives carried out in collaboration with the socio-economic environment. These include participation in conferences, delivery of training sessions, and the organization of cyclical meetings with industry professionals.

An integral part of the University's commitment to maintaining high educational standards is its Internal Quality Assurance System. This system encompasses activities such as regular review and verification of study programs, monitoring of educational delivery, tracking of alumni career trajectories to enhance teaching practices, incorporation of employer feedback into curriculum development, and analysis of internship outcomes. These mechanisms ensure

that the education provided remains relevant, effective, and responsive to the evolving demands of the job market.

At the University of Szczecin, various charitable and socially oriented initiatives are organized on a regular basis. These include numerous donation drives—for example, for children living in orphanages, animals in shelters, or individuals residing in long-term care facilities. Another notable example of socially responsible engagement undertaken by the University of Szczecin is the organization of holiday blood donation campaigns. These initiatives are typically held in the weeks preceding Christmas and are aimed at mobilizing the academic community—students, faculty, and staff alike—to respond to the pressing needs of the healthcare system during a season traditionally associated with solidarity and care for others.

Other socially responsible initiatives at the University include, for instance: the installation of pink boxes in women's restrooms (providing free personal hygiene products such as pads and tampons for those in need), social rooms where employees can prepare meals, and a range of facilities for individuals with disabilities, such as architectural accessibility and psychological support.

An exemplary good practice in the area of university-level corporate social responsibility is the University of Szczecin's Equality Plan for 2022–2024, which provides a strategic framework for promoting inclusive hiring practices. This document explicitly addresses the need to ensure equal access to employment opportunities by eliminating structural barriers and unconscious biases in recruitment and selection procedures. The plan introduces measures such as gender-balanced recruitment committees, the standardization of candidate evaluation criteria, and the systematic collection of data on hiring patterns to monitor equity outcomes. It also emphasizes support for individuals from underrepresented groups, including people with disabilities and those returning to work after caregiving responsibilities. the plan constitutes a concrete and transferable model of inclusive recruitment policy within the broader context of socially responsible governance in higher education.

The examples presented above represent only a selection of the wide range of initiatives undertaken by the University of Szczecin in the field of social responsibility. The University continuously develops and implements new actions, responding to the needs of the socio-economic environment while fulfilling its mission as a modern and engaged academic institution.

The University conducts its socially responsible activities across three main dimensions: environmental, social, and economic. This includes initiatives aimed at environmental sustainability, actions fostering social inclusion and well-being, and dynamic cooperation with the business sector to support regional economic development.

4. Conclusions and Recommendations

In conclusion, the analysis of CSR at the University of Szczecin reveals several noteworthy strengths and areas of good practice. These findings may serve as a foundation for further development of responsible management practices within the academic environment.

One of the most prominent strengths of the University of Szczecin in the area of CSR is the strong and visible commitment of the university's leadership to the principles of social responsibility. This is evidenced by the establishment of dedicated positions, committees, and working groups focused specifically on CSR-related matters. Such institutional structures reflect a strategic approach to embedding social responsibility within the organizational framework of the university.

Another important asset is the incorporation of socially responsible actions into key university documents, including the overarching strategic plan as well as the strategies of individual faculties and institutes. This alignment demonstrates that CSR is not treated as an isolated initiative but rather as an integral component of the university's long-term vision and mission.

Additionally, the university has implemented a number of internal regulations and codes addressed to its internal stakeholders, including staff and students. These documents outline a set of principles, rules, and procedures designed to guide the behavior of members of the academic community. Importantly, they serve an educational and supportive function by promoting appropriate standards of conduct. They also provide practical guidance to employees and students in making ethical and socially responsible decisions in various situations encountered within the university context.

The University of Szczecin also demonstrates a strong connection with its socio-economic environment. Initiatives such as the “Równa Firma” competition exemplify how academic teaching and research are interwoven with CSR values. Through collaborative projects involving both staff and students, CSR-related themes are embedded into educational processes, often forming the basis for theses and case studies. These initiatives enhance the University’s contribution to building responsible organizational cultures within the broader community.

Another important strength of the University’s CSR policy is its proactive and sustained collaboration with external stakeholders. This is exemplified by the establishment of Employer Councils, the organization of public competitions and rankings such as the “Równa Firma” initiative, and numerous charitable actions undertaken in partnership with local communities. By fostering long-term relationships with employers, NGOs, and civic institutions, the University reinforces its role not only as an educational institution but also as a socially responsive and community-embedded organization.

Despite the diversity and broad scope of the initiatives presented, it should be noted that the University of Szczecin has not yet implemented a comprehensive evaluation framework enabling the systematic measurement of the effectiveness and impact of its CSR-related activities. The absence of clearly defined assessment criteria and performance indicators limits the ability to compare individual initiatives, identify areas requiring further intervention, and monitor progress over time. The development and implementation of a coherent evaluation system—based on measurable outcomes and results—would contribute to greater transparency of undertaken activities and strengthen the strategic planning process in this domain.

The University of Szczecin has made considerable progress in implementing CSR practices. However, certain areas still present opportunities for improvement. One such area is the systematic reporting of socially responsible activities. The University has not published annual social responsibility reports addressed to its stakeholders. The introduction of such reports would significantly enhance transparency, facilitate the evaluation of ongoing initiatives, and strengthen stakeholder trust. Social reporting serves as a key instrument for communicating the institution's values, achievements, and commitments, and aligns the University with global standards of responsible governance. The systematic publication of an annual sustainability report, potentially aligned with international standards such as the Global Reporting Initiative (GRI), would enhance both internal accountability and external credibility.

Another area requiring attention is the communication of CSR-related activities through social media platforms, particularly newer channels such as YouTube and TikTok. These platforms represent powerful tools for outreach, especially among younger audiences. By leveraging social media more effectively, the University could broaden public awareness of its socially responsible initiatives, foster greater engagement within the academic community, and position itself as a forward-looking and accessible institution.

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References

1. Ali, M., Mustapha, T.I., Osman, S.B., Hassan, U. (2020). University social responsibility (USR): An Evolution of the concept and its thematic analysis. *Journal of Cleaner Production, 124931*. Doi:10.1016/j.jclepro.2020.124931.
2. Bok, D., (1982). *Beyond the ivory tower. Social Responsibility of the modern universities*. Harward University Press.
3. Brown, E., Cloke, J. (2015). Corporate Social Responsibility in Higher Education. *An International Journal for Critical Geographies, No. 3*.
4. Bukowska-Piestrzyńska, A., Motowidlak, U. (2025). Social responsibility of universities – theoretical and practical approach. *Scientific Papers of Silesian University of Technology. Organization and Management Series, 217*, pp. 15-31.
5. Espinoza Santeli, G., Guachamín Montoya, M. (2018). La responsabilidad social universitaria en Ecuador. *Estudios De La Gestión: Revista Internacional De Administración, 1,* 9-27. Retrieved from: https://revistas.uasb.edu.ec/index.php/eg/article/view/568, 20.05.2025.
6. Kieżel, M., Piotrowski, P., Wiechoczek, J. (2021). Perception of Social Responsibility Strategy in Higher Education: Empirical Study in Poland. *Sustainability, 13(16),* 9417. Retrieved from: https://doi.org/10.3390/su13169417, 21.05.2025.
7. Leja, K. (2008). *Społeczna odpowiedzialność uczelni*. Gdańsk: Wydawnictwo Politechniki Gdańskiej.
8. Lu, J., Ren, L., He, Y., Lin, W., Streimikis, J. (2019). Linking corporate social responsibility with reputation and brand of the firm. *Amfiteatru Economic, 21(51),* pp. 1-26.
9. Meseguer-Sánchez, V., Abad-Segura E., Belmonte-Ureña L.J., Molina-Moreno V. (2020). Examining the research evolution on the socio-economic and environmental dimensions on university social responsibility. *International Journal of Environmental Research and Public Health, No. 13*, DOI: 10.3390/ijerph17134729.
10. Reiser, J. (2007). Managing University Social Responsibility (USR). *International Sustainable Campus Network: Best Practices-Future Challenges.* Retrieved from: www.international-sustainable-campus-network.org/downloads/conference-and-symposia/iscn-conference-2007/108-panel-bl-juan-reiser-pontificia-universidad-catolica-del-peru/file, 19.05.2025.
11. Szelągowska-Rudzka, K., Spodarczyk, E. (2018). Społecznie odpowiedzialny student w społecznie odpowiedzialnej uczelni w świetle wyników badania. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu, No. 516*, pp. 87-98.
12. The Ministry of Education and Science (2025). *University Social Responsibility*. Retrieved from: https://www.gov.pl/web/nauka/spoleczna-odpowiedzialnosc-uczelni, 15.05.2025.

13. University of Szczecin (2025a). *Strategia Rozwoju Uniwersytetu Szczecińskiego 2019-2028.* Retrieved from: https://usz.edu.pl/strategia/, 15.05.2025.
14. University of Szczecin (2025b). *Kodeks etyki nauczyciela akademickiego US*. Retrieved from: https://usz.edu.pl/dokumenty/, 10.05.2025.
15. University of Szczecin (2025c). *Kodeks etyki studenta*. Retrieved from: https://wpia.usz.edu.pl/wp-content/uploads/Uchwa%C5%82a_nr_44.2024_w_sprawie_uchwalenia_Kodeksu_etyki_studenta_Uniwersytetu_Szczeci%C5%84skiego-1.pdf, 11.05.2025.
16. Valencia-Arias, A., Rodríguez-Correa, P.A., Marín-Carmona, A., Zuleta-Orrego, J.I., Palacios-Moya, L., Pérez Baquedano, C.A., Gallegos, A. (2024). University social responsibility strategy: a case study. *Cogent Education, 11(1).* https://doi.org/10.1080/2331186X.2024.2332854.
17. Vargas Vergara, M. (2023). University Social Responsibility. *Oxford Research Encyclopedia of Education.* Retrieved from: https://oxfordre.com/education/view/10.1093/acrefore/9780190264093.001.0001/acrefore-9780190264093-e-810, 22.05.2025.

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TRENDS AND CHALLENGES RELATED TO THE USE OF AI IN PUBLIC SERVICES FROM A CUSTOMER PERSPECTIVE: A NARRATIVE SYSTEMATIC LITERATURE REVIEW

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Purpose: The use of AI in public services is becoming increasingly common and brings many benefits. However, it is associated with various types of problems. One of them is social acceptance of services implemented with the participation of AI. Even the best technological solutions will not bring benefits if customers do not trust them or are unable to use them. The aim of the study is to identify factors that facilitate customer acceptance of public services implemented using AI and problems related to customer resistance to the use of AI technologies in these services.
Design/methodology/approach: This article is based on a narrative systematic literature review. Out of the 173 articles qualified for the study, through the selection and filtering process, 9 research articles that met the inclusion and exclusion criteria were finally qualified for the in-depth analysis. In order to achieve the study objective, a mixed research review method and qualitative synthesis were used.
Findings: Studies have shown that the acceptance of AI in public services depends on several key factors: trust in public institutions, transparency of AI services, privacy and data security, awareness of the usability and operation of AI, and the possibility of choosing service without AI. Acceptance of AI is higher in simple services and lower where individual approach and empathy are needed.
Research limitations/implications: The scope of this review was limited to the Web of Science database. The study covers publications from 2015 to 2025 and does not include review articles, retracted materials, or editorials.
Originality/value: This study, synthesizing different research perspectives, contributes to a better understanding of customer perceptions related to the use of AI in public services. The article identifies potential research gaps and directions for future research. It also proposes recommendations for public managers regarding the process of implementing artificial intelligence in public services.
Keywords: Artificial Intelligence, AI, public administration, public services, customer perception, improvement.
Category of the paper: literature review.

1. Introduction

Artificial intelligence (AI) is becoming one of the key tools for transforming the public sector. The literature indicates numerous examples of improving public services using AI tools that affect how citizens use services provided by public administration offices (Chen et al., 2019; Kachn et al., 2020; Delfos et al., 2022; Progoniuk, Husenko, 2022; Nicolás, Sampaio, 2024). Much attention in this regard is paid to the use of Chatbots (Van Noordt, Misuraca, 2019; Henman, 2020; Cortés-Cediel et al., 2023; Cruz Meléndez et al., 2024). Yigitcanlar et al. (2024), based on a review of grey literature, identified 262 actual AI implementations in 170 local governments around the world. It can therefore be stated that the transformation of public services focused on the use of AI is progressing dynamically, both in the sphere of scientific research and practical applications.

Although AI is developing dynamically and offers opportunities to improve the efficiency of public administration and service provision, significant barriers to its application can be identified, including concerns about bias, transparency, public acceptance and accountability (Caiza et al., 2024). The use of artificial intelligence in public services is therefore associated with a number of challenges faced by government and local government units.

Customer perception is one of the most frequently mentioned problems in the literature related to the implementation of AI solutions in public services. Articles presenting empirical research related to the implementation of AI tools in public services often indicate ethical concerns (Fatima et al., 2021; Alshahrani et al., 2022), problems with customer's lack of trust in AI (Gesk, Leyer, 2022), ensuring privacy and protection of personal data (Willems et al., 2023; El El Gharbaoui et al., 2024), and problems with stakeholder engagement (Berman et al., 2024). They are therefore largely related to how customers perceive the use of AI in public services and how smart services will affect their satisfaction.

Empirical studies on customer perceptions related to the use of AI in public services are scattered and heterogenous. The analysis of the Web of Science database showed that several review articles cover different aspects of the use of AI in public services. Of the 17 reviews identified in the WoS database, those that did not refer to public services directly implemented by the government and local government institutions, i.e.: education, libraries, health care, urban transport, etc. Systematic literature reviews in the area of AI in public services have been conducted, among others, in the areas of digitalization, accountability and accounting (Agostino et al., 2022), the impact of AI on public sector employment (Reis et al., 2021), corruption (Adam, Fazekas, 2021) and smart cities (Das, 2024; Alsabt et al., 2024). AI-powered IoT solutions (Ma et al., 2020) and problems related to interpreting black box models (Hassija et al., 2024) were also considered in the area of smart public services. De Sousa et al. (2019) point to a growing trend of interest in AI in the public sector, with India and the US being the most active countries. Madan and Ashok (2023) identified five AI-related tensions that affect

the creation of public value as a result of the dissemination of AI. In turn, Caisa et al. (2024) present a comprehensive review of the literature on the impact of artificial intelligence on decision-making processes in public administration. The authors' main conclusions indicate that the use of AI can: contribute to increased efficiency and precision in administrative decision-making, pose a challenge related to algorithmic biases, generate a lack of transparency and accountability for possible errors or abuses, pose a threat to privacy and data security, and generate the need to introduce appropriate regulations and standards in the area of AI.

The conducted analysis indicates the need to collect and systematize the existing body of empirical research that relates to how users of public services react to the use of artificial intelligence tools in these services. Therefore, this study aims to identify factors that facilitate customer acceptance of AI-based public services and problems related to customer resistance to the use of AI technologies in these services through a narrative systematic literature review. The analysis of existing studies will allow for a better understanding of the problems and barriers resulting from customer resistance to the use of AI solutions in public services, which may limit its effective implementation. The following sections of the publication discuss the theoretical framework necessary for the discussion of this topic. Then, the methodological aspects of the study, including data collection and analysis procedures, are presented. Finally, the results of the review are presented and an agenda for future research is proposed.

2. Theoretical framework

2.1. Artificial intelligence

Artificial intelligence is a term that was first used by J. McCarthy in the 1950s (McCarthy, 2007). It can be understood as a kind of philosophy of machines that are supposed to think, behave and act in the same or similar way as humans (Dhamija, Bag, 2020). Currently, artificial intelligence is one of the most dynamically developing areas of technology, discussed in the context of various spheres of human activity (Thayyib et al., 2023; Lawelai et al., 2023; Knani et al., 2022; Vasishta et al., 2024; Bawack et al., 2022). Moreover, the term covers a wide range of issues, from machine learning algorithms to ethics and the impact of AI on society. In the service sector, artificial intelligence can have various applications. Many analyses indicate that its implementation improves the efficiency of service processes and the quality of customer service (Kumar et al., 2024; Kulal et al., 2024). Examples of intelligent tools used to improve customer service quality include chatbots and virtual assistants (Misischia et al., 2022), e-commerce recommendation systems (Necula, 2023), and algorithms that optimize logistics processes (Chen et al., 2024). In banking and finance, AI helps detect fraud and manage risk (Aziz, Andriansyah, 2023), and in the hotel industry and tourism, it enables the creation of

unique customer profiles and the provision of personalized recommendations and dynamic price adjustments (Das et al., 2024).

2.2. Characteristics and classification of public services

Public services are basic services provided by government and local government bodies or entities authorized by them. Their purpose is to satisfy the basic needs of citizens and to ensure social well-being. Public services can be defined as public goods that have a specific value regardless of the number of recipients and in relation to which it is impossible to exclude anyone from using them (Lissowski, 2017). Public services therefore play a key role in the functioning of the state and ensuring the well-being of its citizens. Public services in the literature on the subject are classified differently by different authors. Due to the scope of services provided, the most frequently cited classification of public services in Poland is the division into: (1) administrative services, which are directly related to the performance of administrative activities, e.g. issuing certificates, concessions, administrative decisions, documents, (2) social services, which are aimed at meeting social needs, e.g. health care, education, culture, social assistance and care, and (3) technical services, which are related to transport, energy, water management, waste management (Kożuch, B., Kożuch, A., 2011). Diepart et al. (2016) divided public services into the following categories: health, education, public administration, social affairs and security. In turn, depending on the method of provision, public services can be divided into general, which are provided without a specific request and concern all or most citizens, and specific, which are explicitly requested by citizens and affect only one or a few citizens (Halaris et al., 2007). Taking this division into account, it can be stated that technical and social services can be classified as general services because they are addressed to the general public (e.g. providing educational services or water to residents in a given area) and administrative services can be treated as specific (e.g. issuing a building permit at the request of the client).

3. Methods

This study conducted a narrative systematic review of the literature (Mishra, V., Mishra, M.P., 2023). To achieve the study objective, the mixed research review method (Grant, Booth, 2009) was used due to the fact that the initial literature review indicated the use of both quantitative and qualitative research in relation to the analysed issue. The process of conducting a systematic literature review was designed based on the guidelines proposed by Synder (2019) and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology (Moher et al., 2009).

The first step of the research was to define the research objective and questions. The PICO method was used to correctly formulate the research questions. The result is presented in Figure 1.

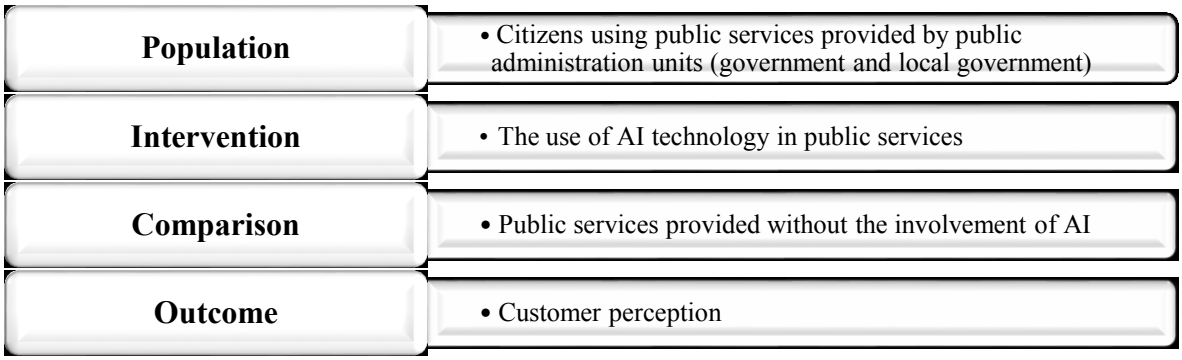

Figure 1. PICO Model.

Source: own work.

The PICO model presented in Figure 1 allowed for the formulation of two research questions:

RQ1: What factors influence positive customer perceptions related to the use of AI technology in public services compared to services implemented without the participation of AI in public administration units?

RQ2: What factors influence the negative customer perception related to the use of AI technologies in public services compared to services implemented without the participation of AI in public administration units?

In order to achieve the aim presented in the introduction and answer the research questions, a literature search strategy was developed in the next step. The Web of Science database was selected for the study because it presents high-quality and influential scientific articles. It was decided to use two general keywords in the search criteria: "public services" and "artificial intelligence". The search criteria included all publications excluding review articles, retracted materials and editorials. Studies were limited to the 2015-2025 period, with no restrictions on the language of the publication. The inclusion criteria included: quantitative, qualitative or mixed empirical studies on customer perceptions related to the use of AI technologies in public services in central or local government units. The exclusion criteria included: works on the digitization of public services that do not discuss AI, studies not focused on the application of AI in services provided directly in government and local government administration, such as smart cities, medicine, universities, police, healthcare, macro-level studies on legal regulations, policies and guidelines regarding AI.

4. Results

4.1. Descriptive analysis of publications included in the review

The article selection process began with an analysis of the publication set for duplicates that were not found. In the next step, titles, abstracts and keywords were analysed and articles were selected in accordance with the adopted inclusion and exclusion criteria. In the next step, data relevant to the achievement of the research objective and the research questions were extracted. The procedure is presented in Figure 2.

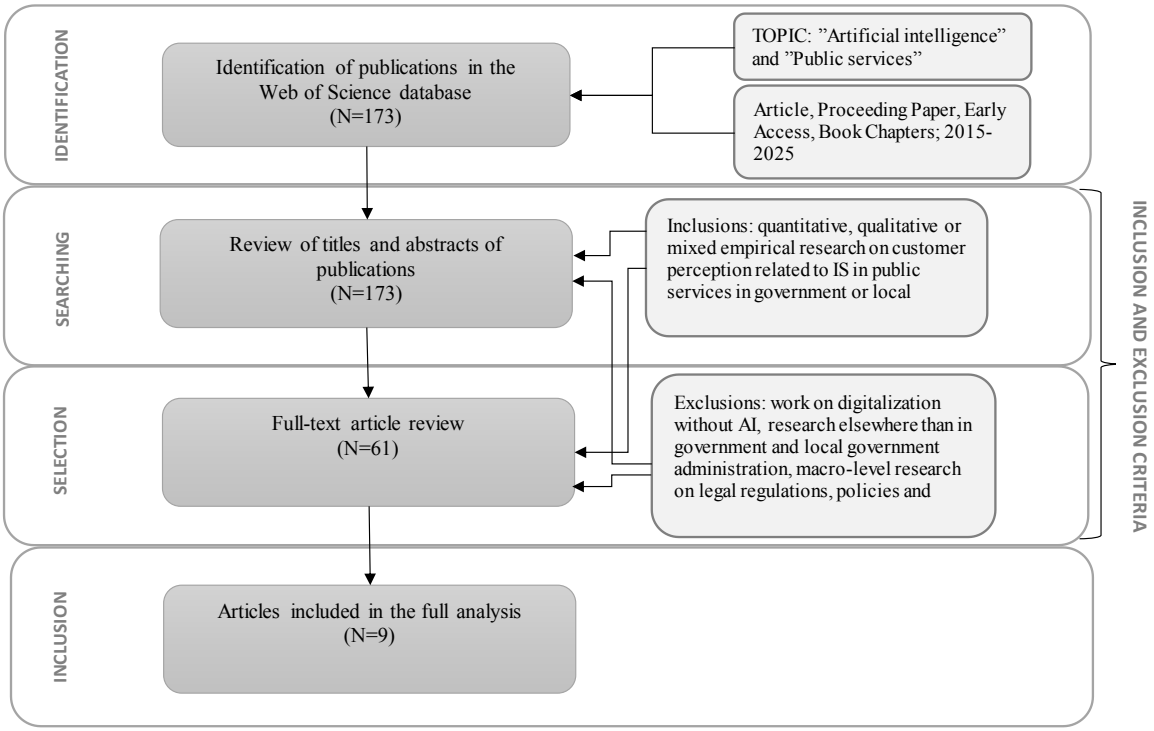

Figure 2. Flowchart presenting the research selection process.

Source: own work.

As a result of the first stage of the search, 173 publications were identified. Figure 3 presents the quantitative distribution of publications and their citations by date of issue.

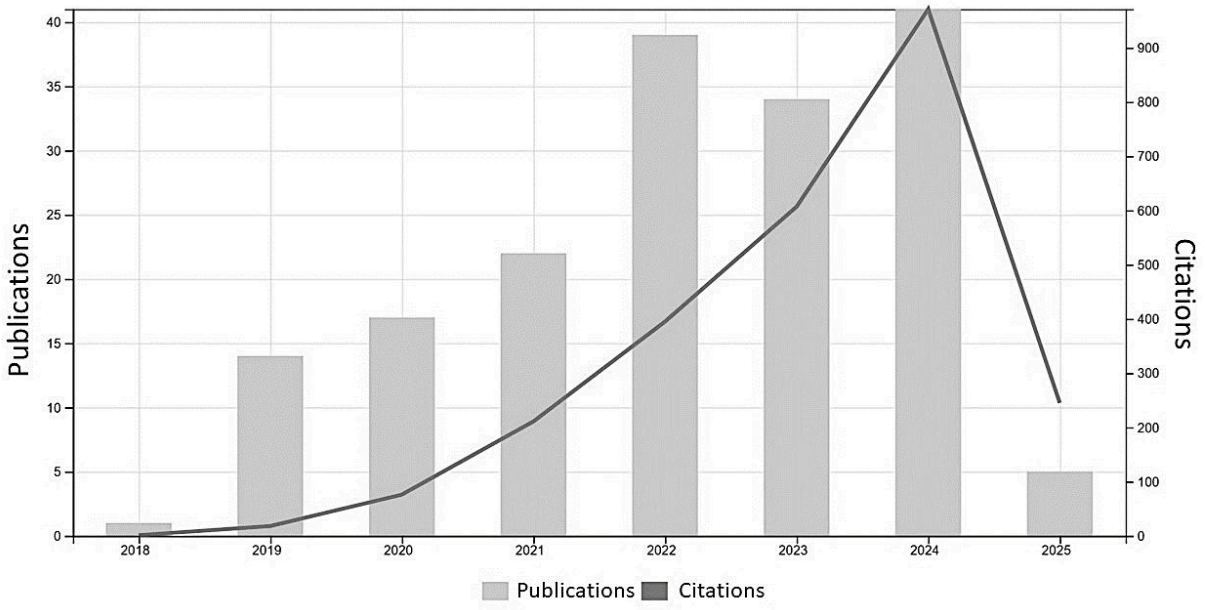

Figure 3. Quantitative distribution of publications and citations by date of issue.
Source: Web of Sience.

After reviewing the titles and abstracts of the identified articles and taking into account the inclusion and exclusion criteria, 61 papers were qualified for full-text analysis. Four texts were excluded from this group because their full content was not available. The full texts of the articles were analysed to ensure that they met all the study criteria. Nine publications were qualified for the final analysis.

4.2. Findings of the qualitative synthesis

All of the articles that qualified for analysis were published in the years 2021-2024. Seven research projects were based on quantitative research addressed to large groups of respondents. The main tool used for their implementation was a survey questionnaire, and the obtained data were analysed using statistical methods. In the case of the other two articles, qualitative research methods were used to achieve the research objectives, and interviews were conducted with respondents.

The analysis of the empirical research results presented in Table 1 allowed us to identify several important factors that may influence how customers using public services perceive the use of artificial intelligence in the implementation of these services. First, a positive or negative reaction to the use of AI in public services is determined by trust in the government. Schmager et al. (2024) argue that a high level of trust in the government fostered a positive attitude towards the implementation of AI in public services. This trust was based on the belief that the government acts in the best interests of citizens. They also emphasized that the key factors for responsible and effective implementation of AI in public services are ensuring transparency and human participation in decision-making processes.

Table 1.
Context of research in the area of customer perceptions of the use of AI in public services

Author	Country	Purpose/research questions/hypotheses	Method	Number of respondents
El El Gharbaoui et al. (2024)	Morocco	The aim of the study is to identify the impact of AI chatbot implementation on citizen satisfaction in the public sector in Morocco, with particular emphasis on the moderating variable of trust in AI chatbots.	Quantitative	N=157
Horvath et al. (2023)	United Kingdom	H1 – Greater human involvement increases the acceptance of AI in decision-making and the related perception of its fairness; H2 – Greater human involvement mitigates the negative impact of some AI characteristics, such as inaccuracy, high cost, or data sharing.	Quantitative	N=2143
König (2023)	Germany	The aim of the study is to identify whether citizens' conceptions of democracy are related to their views on AI in government and politics.	Quantitative	N=1115
Kim et al. (2023)	South Korea	The aim of the study is to identify the influence of six functional factors, namely usability, ease of use, service reliability, service quality, responsiveness and security, on the continued use of AI-based public services through the mediating effect of user satisfaction.	Quantitative	N=350
Willems et al. (2023)	Austria	1. How do perceived usability, data sharing requirements, and citizens' general privacy concerns affect their willingness to use AI-based public services? 2. Do citizens act on privacy concerns in specific contexts?	Quantitative	N=1048
Chatterjee et al. (2022)	India	RQ1. How can the use of AI-enabled services by various government departments promote citizen satisfaction? RQ2. Can the deep and broad assimilation of AI-enabled government services affect the operational and strategic public services provided to citizens? RQ3. Are there any moderating effects of risk factors that may affect the quality of AI-enabled services and public values?	Quantitative	N=315
Gesk, Leyer (2022)	Australia	RQ1. Is AI accepted for (specific and generic) services in the public sector? RQ2. Why is AI accepted or rejected in this context?	Quantitative	N=395
Schmager et al. (2024)	Norway	The aim of the study is to obtain citizens' opinions on the use of AI in public services based on a designed social service prototype.	Qualitative	N=20
Drobotowicz et al. (2021)	Finland	The aim of this study was to determine what requirements citizens have for trustworthy AI services in the public sector.	Qualitative	N=21

Source: Own work based on literature analysis.

The transparency of AI services is also highlighted by Dobrotowicz et al. (2021), who claim that customers of public services expect explanations regarding how AI systems work and how data is used. Therefore, it is indicated that there is a need to provide mechanisms for controlling personal data, because customers want to know who and how processed their data (Drobotowicz et al., 2021; Willems et al., 2023).

The level of acceptance of public services implemented using AI varies depending on the type of services. The use of AI raises more concerns in areas that require a high level of trust and privacy, e.g. in administrative decisions or medicine (Gesk, Leyer, 2022; Willems et al., 2023). Artificial intelligence is more accepted in simple and repetitive services (such as issuing an identity document, certificate, etc.). However, in the case of more complex situations, citizens prefer interaction with humans (Gesk, Leyer, 2022). This may be due, among other things, to the fact that customers want to be able to appeal to a human in the case of decisions made by AI (Drobotowicz et al., 2021). Some authors also argue that the presence of a human in service processes is important, especially in matters requiring empathy or contextual assessment (Schmager et al., 2024; Willems et al., 2023). Chatterjee et al. (2022) also argue that the acceptance of AI in the public service environment is facilitated by the visibility of the benefits of its use, such as speed of implementation or convenience. These conclusions are consistent with the results of Kim et al. (2023), according to which citizens' satisfaction with AI services contributes to the growth of public value if the systems are well designed and integrated with social needs. It is also worth mentioning that the broader and more comprehensive the implementation of AI, the greater the user satisfaction (Chatterjee et al., 2022).

Interesting research on the acceptance of AI in public services refers to the privacy paradox. Willems et al. (2023) indicate that customers declare concerns about the privacy and protection of their data in relations to the use of AI in public services. However, these concerns do not always translate into actual user behaviour. Studies have shown that despite these concerns, participants did not show significant sensitivity to the amount of personal data required by the application. The key factor influencing respondents' decision to use AI during service provision was in this case the perceived usefulness of the application.

The studies also show concerns among users of public services related to automation and the loss of human supervision. König (2023) indicates that people do not want administrative decisions to be made solely by algorithms. He indicates that while respondents showed moderate support for the use of AI in routine administrative tasks, the acceptance of the use of AI at higher decision-making levels, such as supporting or replacing politicians in decision-making, was much lower. In turn, Gesk and Leyer (2022) indicate that negative perceptions of AI are more often due to fears than to a lack of knowledge about the technology.

In summary, the results of the analysis indicate that the use of AI in public administration can help improve the quality of public services and increase customer satisfaction if certain conditions are met that ensure the acceptance of AI. These conditions include: fast and convenient service, transparency of AI-based systems and providing customers with the possibility of interaction with a human. Otherwise, lack of trust, privacy concerns and insufficient control over AI decisions can lead to customer dissatisfaction and lack of acceptance for AI. The level of trust in public institutions is also important.

5. Discussion

The aim of this study was to identify factors that facilitate customer acceptance of public services implemented using AI and to identify problems related to customer resistance to the use of AI technologies in these services. The conducted systematic review and analysis of the literature showed that there are several key factors that can influence both positive and negative customer perceptions related to the use of AI in public services. These include: trust in public institutions, transparency of AI services, privacy and data security, awareness of the usefulness and operation of AI, and the ability to choose service without AI. These factors can affect both positive (RQ1) and negative (RQ2) customer perceptions, depending on whether specific conditions contributing to the acceptance of AI services are met.

In order to increase the chances of a positive customer response to the use of AI in public services, offices should work on strengthening the general trust of citizens in their institution. It is good to implement AI in public services in stages, through evolution. A simplified proposal of the process of improving public services through the implementation of artificial intelligence tools is shown in Figure 4. This process is part of Deming's continuous improvement cycle, PDCA (Moen, Norman, 2006).

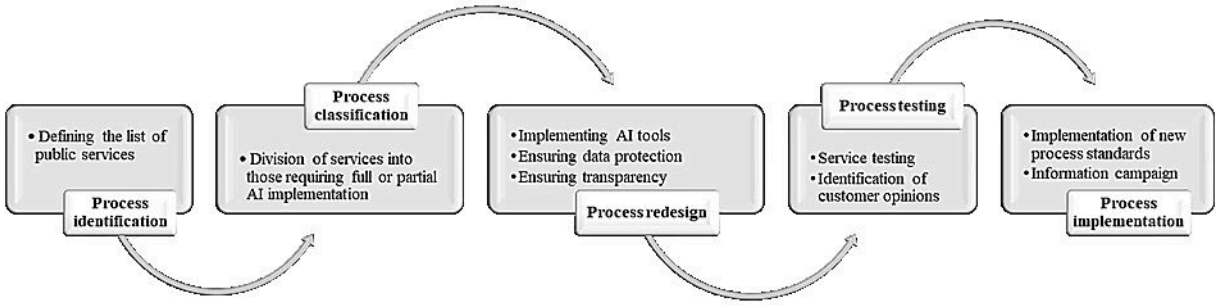

Figure 4. The process of improving public services through the implementation of AI tools.
Source: own work.

It is proposed to start this process by identifying services in a given public institution and then classifying them in terms of the possibility of using AI. The argument in favour of such a solution is the level of acceptance of AI in public services found in studies, which varies depending on the type of service. Acceptance of AI in public services occurs faster in the case of simple, routine services. In more complex cases, AI should be only a tool supporting officials, not replacing them. This will allow for maintaining a balance between process efficiency and the needs of citizens. The next stage is the redesign of processes combined with the implementation of AI tools. It is important to design solutions at this stage that ensure the protection of personal data and the transparency of the process, especially in relation to the stages implemented using AI. It is also recommended that in the case of complex services requiring empathy or an individual approach, customers should be allowed to use an alternative path, without the participation of AI. The fourth step of the improvement process consists in

testing the designed public service and verifying its correctness, taking into the account the customer's opinion. It is worth using, for example, customer experience research methods (Ludwiczak, 2021) in this step. After the testing stage is completed and any corrective solutions have been introduced, the service can be implemented. The key action at this stage is a properly designed information campaign aimed at citizens. It should provide information on how AI solutions were used, what benefits customers gain from it, how their personal data and privacy are protected, and how they can appeal against possible erroneous AI decisions.

6. Conclusion

In view of the growing interest in the application of AI in public services (Figure 3), this study contributes to both the literature on the use of technological innovations in improving public services and the management practice of central and local government units. The analysis identified key factors influencing customer perceptions of AI use in public services. It supplements existing literature reviews, for example on the tensions related to AI in public value creation (Madan, Ashok, 2023) and addresses the need for ongoing research and dialogue on the ethical, social and practical implications of AI in government, aimed at ensuring responsible and inclusive adoption of AI-based public services (Caisa et al., 2024).

By synthesizing different research perspectives, it was possible to identify potential research gaps. It was noted that out of 173 articles qualified for analysis, only 9 directly referred to empirical research on customer perception related to the use of AI in public services. These studies were characterized by different methodological approaches and large geographical dispersion. There is also a lack of research on how customer perceptions of AI-supported public services evolve over the long term. Based on the conducted analysis, potential directions for future research can be identified, which may contribute to a better understanding of the conditions necessary for the effective and ethical implementation of AI in public administration. One such direction could involve identifying the factors that influence the use of AI in public services across different cultural contexts (through comparative international studies) or among various social groups (e.g., individuals at risk of social exclusion). It is also worth examining how public perceptions of AI in public services change over time.

In addition, based on the results obtained, recommendations can be formulated for public policy and the management practices of public institutions concerning the implementation of artificial intelligence in public services. As previously noted, the acceptance of AI in public services depends on various factors, including trust in institutions, transparency of operations, data protection, public awareness, and the ability to choose a traditional service path. Therefore, the state should introduce policies aimed at strengthening public trust in institutions and

ensuring the transparency of AI algorithms. It is also essential to develop appropriate legal frameworks regarding privacy and the accountability of AI systems. Citizens must be provided with clear regulations defining responsibility for decisions made by AI, along with accessible appeal mechanisms. Moreover, within the scope of the state's information and education policy, it is advisable to support initiatives that promote knowledge about AI and its applications in public services. From the perspective of managing public institutions, a phased and evolutionary approach to implementing AI is crucial. This should include pilot programs, testing phases, and thorough evaluations of the innovations introduced. In cases where services require it, citizens should have the option to choose between AI-based and traditional forms of service. Public offices must also ensure system transparency, data protection, and straightforward procedures for appealing decisions. The successful implementation of AI also requires the development of digital competencies among public sector employees and the execution of effective public information campaigns, which are key to enhancing both acceptance and understanding of AI in public services.

This study has some limitations. First, the scope of this systematic review was limited to the Web of Science database. Therefore, valuable empirical research results published in journals, conference proceedings, or books that are not indexed in this database may not have been included in the study. Second, the study covers publications from 2015 to 2025 and does not include review articles, retracted materials, or editorials. Another limitation concerns the selected keywords. In order to increase the chances of examining as many articles as possible, general and popular keywords that are commonly used in articles on the topic under study were deliberately selected. However, it is possible that the selected keywords may not cover the detailed aspects of the topic discussed. Since this study is based on qualitative analysis, quantitative data analysis is needed in future studies to confirm the obtained results.

References

1. Adam, I., Fazekas, M. (2021). Are emerging technologies helping win the fight against corruption? A review of the state of evidence. *Information Economics and Policy*, *57*, 100950, https://doi.org/10.1016/j.infoecopol.2021.100950.
2. Agostino, D., Saliterer, I., Steccolini, I. (2022). Digitalization, accounting and accountability: A literature review and reflections on future research in public services. *Financial Accountability & Management*, *38(2),* pp. 152-176, https://doi.org/10.1111/faam.12301.
3. Alsabt, R., Adenle, Y.A., Alshuwaikhat, H.M. (2024). Exploring the roles, future impacts, and strategic integration of artificial intelligence in the optimization of Smart City—from

systematic literature review to conceptual model. *Sustainability*, *16(8),* 3389, https://doi.org/10.3390/su16083389.

4. Alshahrani, A., Dennehy, D., Mäntymäki, M. (2022). An attention-based view of AI assimilation in public sector organizations: The case of Saudi Arabia. *Government Information Quarterly*, *39(4),* 101617, https://doi.org/10.1016/j.giq.2021.101617.
5. Aziz, L.A.R., Andriansyah, Y. (2023). The role artificial intelligence in modern banking: an exploration of AI-driven approaches for enhanced fraud prevention, risk management, and regulatory compliance. *Reviews of Contemporary Business Analytics*, *6(1),* pp. 110-132, Retrieved from: https://core.ac.uk/download/pdf/578755756.pdf.
6. Bawack, R.E., Wamba, S.F., Carillo, K.D.A., Akter, S. (2022). Artificial intelligence in E-Commerce: a bibliometric study and literature review. *Electronic markets*, *32(1),* pp. 297-338, https://doi.org/10.1007/s12525-022-00537-z.
7. Berman, A., de Fine Licht, K., Carlsson, V. (2024). Trustworthy AI in the public sector: An empirical analysis of a Swedish labor market decision-support system. *Technology in Society*, *76*, 102471, https://doi.org/10.1016/j.techsoc.2024.102471.
8. Caiza, G., Sanguña, V., Tusa, N., Masaquiza, V., Ortiz, A., Garcia, M.V. (2024, September). Navigating Governmental Choices: A Comprehensive Review of Artificial Intelligence's Impact on Decision-Making. *Informatics*, *Vol. 11, No. 3,* p. 64, https://doi.org/10.3390/informatics11030064.
9. Chatterjee, S., Khorana, S., Kizgin, H. (2022). Harnessing the potential of artificial intelligence to foster citizens' satisfaction: an empirical study on India. *Government information quarterly*, *39(4),* 101621, https://doi.org/10.1016/j.giq.2021.101621.
10. Chen, T., Ran, L., Gao, X. (2019, June). *AI innovation for advancing public service: The case of China's first Administrative Approval Bureau.* Proceedings of the 20th Annual International Conference on Digital Government Research, pp. 100-108, https://doi.org/10.1145/3325112.3325243.
11. Chen, W., Men, Y., Fuster, N., Osorio, C., Juan, A.A. (2024). Artificial intelligence in logistics optimization with sustainable criteria: A review. *Sustainability*, *16(21),* 9145, https://doi.org/10.3390/su16219145.
12. Cortés-Cediel, M.E., Segura-Tinoco, A., Cantador, I., Bolívar, M.P.R. (2023). Trends and challenges of e-government chatbots: Advances in exploring open government data and citizen participation content. *Government Information Quarterly, 40(4),* 101877, https://doi.org/10.1016/j.giq.2023.101877.
13. Cruz Meléndez, C., Jiménez Canseco, J.M., Martínez Gutiérrez, R. (2024). La implementación de chatbots en gobiernos municipales mexicanos. Exploración y diagnóstico de uso. *Revista Mexicana de Análisis Político y Administración Pública*, *13(26),* DOI: 10.15174/remap.v13i26.441.

14. Das, D.K. (2024). Exploring the symbiotic relationship between digital transformation, infrastructure, service delivery, and governance for smart sustainable cities. *Smart Cities*, *7(2),* pp. 806-835, https://doi.org/10.3390/smartcities7020034.
15. Das, I.R., Talukder, M.B., Kumar, S. (2024). Implication of artificial intelligence in hospitality marketing. *Utilizing smart technology and ai in hybrid tourism and hospitality*, pp. 291-310, IGI Global, DOI: 10.4018/979-8-3693-1978-9.ch014.
16. De Sousa, W.G., de Melo, E.R.P., Bermejo, P.H.D.S., Farias, R.A.S., Gomes, A.O. (2019). How and where is artificial intelligence in the public sector going? A literature review and research agenda. *Government Information Quarterly*, *36(4),* 101392, https://doi.org/10.1016/j.giq.2019.07.004.
17. Delfos, J., Zuiderwijk, A., Van Cranenburgh, S., Chorus, C. (2022, October). *Perceived challenges and opportunities of machine learning applications in governmental organisations: an interview-based exploration in the Netherlands.* Proceedings of the 15th International Conference on Theory and Practice of Electronic Governance, pp. 82-89, https://doi.org/10.1145/3560107.3560122.
18. Dhamija, P., Bag, S. (2020). Role of artificial intelligence in operations environment: a review and bibliometric analysis. *The TQM Journal*, *32(4),* 869-896, https://doi.org/10.1108/TQM-10-2019-0243.
19. Diepart, J.C., Koditek, W., Hänert, T., Rock, F. (2016). *District & Municipal Land use Master Plan and land use plan handbook.* Retrieved from: https://hdl.handle.net/2268/199644.
20. Drobotowicz, K., Kauppinen, M., Kujala, S. (2021). Trustworthy AI Services in the Public Sector: What Are Citizens Saying About It? In: F. Dalpiaz, P. Spoletini (eds.), *Requirements Engineering: Foundation for Software Quality.* REFSQ 2021. *Lecture Notes in Computer Science, vol. 12685*. Cham: Springer. https://doi.org/10.1007/978-3-030-73128-1_7.
21. El El Gharbaoui, O., El Boukhari, H., Salmi, A. (2024). Chatbots and Citizen Satisfaction: Examining the Role of Trust in AI-Chatbots as a Moderating Variable. *TEM Journal*, *13(3),* pp. 1825-1836, DOI: 10.18421/TEM133-11.
22. Fatima, S., Desouza, K.C., Denford, J.S., Dawson, G.S. (2021). What explains governments interest in artificial intelligence? A signaling theory approach. *Economic analysis and policy*, *71*, pp. 238-254, https://doi.org/10.1016/j.eap.2021.05.001.
23. Gesk, T.S., Leyer, M. (2022). Artificial intelligence in public services: When and why citizens accept its usage. *Government Information Quarterly*, *39(3),* 101704, https://doi.org/10.1016/j.giq.2022.101704.
24. Grant, M.J., Booth, A. (2009). A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Information & Libraries Journal*, *26(2),* pp. 91-108, https://doi.org/10.1111/j.1471-1842.2009.00848.x.

25. Halaris, C., Magoutas, B., Papadomichelaki, X., Mentzas, G. (2007). Classification and synthesis of quality approaches in e- government services. *Internet Research*, *17(4),* pp. 378-401, https://doi.org/10.1108/10662240710828058.
26. Hassija, V., Chamola, V., Mahapatra, A. (2024). Interpreting Black-Box Models: A Review on Explainable Artificial Intelligence. *Cogn. Comput., 16*, pp. 45-74, https://doi.org/10.1007/s12559-023-10179-8.
27. Henman, P. (2020). Improving public services using artificial intelligence: possibilities, pitfalls, governance. *Asia Pacific Journal of Public Administration*, *42(4),* pp. 209-221, https://doi.org/10.1080/23276665.2020.1816188
28. Horvath, L., James, O., Banducci, S., Beduschi, A. (2023). Citizens' acceptance of artificial intelligence in public services: Evidence from a conjoint experiment about processing permit applications. *Government Information Quarterly*, *40(4),* 101876, https://doi.org/10.1016/j.giq.2023.101876.
29. Kahn, L.H., Savas, O., Morrison, A., Shaffer, K.A., Zapata, L. (2020, December). *Modelling hybrid human-artificial intelligence cooperation: a call center customer service case study*. 2020 IEEE International Conference on Big Data (Big Data), pp. 3072-3075, IEEE, DOI: 10.1109/BigData50022.2020.9377747.
30. Kim, Y., Myeong, S., Ahn, M.J. (2023). Living labs for AI-enabled public services: functional determinants, user satisfaction, and continued use. *Sustainability, 15(11),* 8672, https://doi.org/10.3390/su15118672.
31. Knani, M., Echchakoui, S., Ladhari, R. (2022). Artificial intelligence in tourism and hospitality: Bibliometric analysis and research agenda. *International Journal of Hospitality Management*, *107*, 103317, https://doi.org/10.1016/j.ijhm.2022.103317.
32. König, P.D. (2023). Citizen conceptions of democracy and support for artificial intelligence in government and politics. *European Journal of Political Research*, *62(4),* pp. 1280-1300, https://doi.org/10.1111/1475-6765.12570.
33. Kożuch, B., Kożuch, A. (2011). Istota współczesnych usług publicznych. In: B. Kożuch, A. Kożuch (Eds.), *Usługi publiczne. Organizacja i zarządzanie* (pp. 32-44). Kraków: Instytut Spraw Publicznych Uniwersytetu Jagiellońskiego.
34. Kulal, A., Rahiman, H.U., Suvarna, H., Abhishek, N., Dinesh, S. (2024). Enhancing public service delivery efficiency: Exploring the impact of AI. *Journal of Open Innovation: Technology, Market, and Complexity*, *10(3),* 100329, https://doi.org/10.1016/j.joitmc. 2024.100329.
35. Kumar, S., Talukder, M.B., Tyagi, P.K. (2024). The impact of artificial intelligence on improving efficiency in service and implementing best practices in service marketing. *AI Innovations in Service and Tourism Marketing*, pp. 57-79. IGI Global, DOI: 10.4018/979-8-3693-7909-7.ch004.

36. Lawelai, H., Iswanto, I., Raharja, N.M. (2023). Use of Artificial Intelligence in Public Services: A Bibliometric Analysis and Visualization. *TEM Journal*, *12(2),* 798, DOI: 10.18421/TEM122-24.
37. Lissowski, O. (2017). Usługi publiczne i usługi w interesie ogólnym–koncepcja i niektóre problemy instytucjonalne marketyzacyjnej modernizacji świadczenia usług publicznych w Unii Europejskiej. *Zeszyty Naukowe Politechniki Poznańskiej*. *Organizacja i Zarządzanie, 74*, pp. 9-27, DOI: https://doi.org/10.21008/j.0239-9415.2017.074.01.
38. Ludwiczak, A. (2021). Using customer journey mapping to improve public services: A critical analysis of the literature. *Management*, *25(2),* DOI: 10.2478/manment-2019-0071.
39. Ma, Y., Ping, K., Wu, C., Chen, L., Shi, H., Chong, D. (2020). Artificial Intelligence powered Internet of Things and smart public service. *Library Hi Tech*, *38(1),* pp. 165-179, DOI:10.1108/LHT-12-2017-0274.
40. Madan, R., Ashok, M. (2023). AI adoption and diffusion in public administration: A systematic literature review and future research agenda. *Government Information Quarterly, 40(1),* 101774, https://doi.org/10.1016/j.giq.2022.101774.
41. McCarthy, J. (2007). *What is artificial intelligence*. Retrieved from: https://cse.unl.edu/~choueiry/S09-476-876/Documents/whatisai.pdf
42. Mishra, V., Mishra, M.P. (2023). PRISMA for review of management literature–method, merits, and limitations–an academic review. *Advancing Methodologies of Conducting Literature Review in Management Domain*, pp. 125-136, https://doi.org/10.1108/S2754-586520230000002007.
43. Misischia, C.V., Poecze, F., Strauss, C. (2022). Chatbots in customer service: Their relevance and impact on service quality. *Procedia Computer Science, 201*, pp. 421-428, https://doi.org/10.1016/j.procs.2022.03.055.
44. Moen, R., Norman, C. (2006, May). *Evolution of the PDCA cycle*. Retrieved from: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=52beeeb73aada4c70c9bfa663b7487e936abca37.
45. Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., Prisma Group (2010). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *International Journal Of Surgery*, *8(5),* pp. 336-341, https://doi.org/10.1016/j.ijsu.2010.02.007.
46. Necula, S.C., Păvăloaia, V.D. (2023). AI-driven recommendations: A systematic review of the state of the art in E-commerce. *Applied Sciences*, *13(9),* 5531, https://doi.org/10.3390/app13095531.
47. Nicolás, M.A., Sampaio, R.C. (2024). Balancing efficiency and public interest: The impact of AI automation on social benefit provision in Brazil. *Internet Policy Review*, *13(3),* DOI: 10.14763/2024.3.1799.

48. Progoniuk, L., Husenko, A. (2022). Main directions for improving public administration mechanisms in Ukraine. *International Journal of Advanced and Applied Sciences, 9(8),* pp. 41-48, https://doi.org/10.21833/ijaas.2022.08.005.
49. Reis, J., Santo, P.E., Melão, N. (2021). Influence of artificial intelligence on public employment and its impact on politics: a systematic literature review. *Brazilian Journal of Operations & Production Management*, *18(3),* pp. 1-22, DOI: https://doi.org/10.14488/BJOPM.2021.010.
50. Schmager, S., Grøder, C.H., Parmiggiani, E., Pappas, I., Vassilakopoulou, P. (2024). Exploring citizens' stances on AI in public services: A social contract perspective. *Data & Policy*, *6*, e19, DOI: https://doi.org/10.1017/dap.2024.13.
51. Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research, 104*, pp. 333-339, https://doi.org/10.1016/j.jbusres.2019.07.039.
52. Thayyib, P.V., Mamilla, R., Khan, M., Fatima, H., Asim, M., Anwar, I., Shamsudheen, M. K., Khan, M. A. (2023). State-of-the-Art of Artificial Intelligence and Big Data Analytics Reviews in Five Different Domains: A Bibliometric Summary. *Sustainability*, *15(5),* 4026, https://doi.org/10.3390/su15054026.
53. Van Noordt, C., Misuraca, G. (2019). *New wine in old bottles: Chatbots in government: Exploring the transformative impact of chatbots in public service delivery.* Electronic Participation: 11th IFIP WG 8.5 International Conference, ePart 2019, San Benedetto Del Tronto, Italy, September 2-4, 2019, Proceedings 11, pp. 49-59, Springer International Publishing, DOI: ff10.1007/978-3-030-27397-2_5.
54. Vasishta, P., Dhingra, N., Vasishta, S. (2024). Application of artificial intelligence in libraries: a bibliometric analysis and visualisation of research activities. *Library Hi Tech*, https://doi.org/10.1108/LHT-12-2023-0589.
55. Willems, J., Schmid, M.J., Vanderelst, D., Vogel, D., Ebinger, F. (2023). AI-driven public services and the privacy paradox: do citizens really care about their privacy? *Public Management Review*, *25(11),* pp. 2116-2134, https://doi.org/10.1080/14719037.2022.2063934.
56. Yigitcanlar, T., David, A., Li, W., Fookes, C., Bibri, S.E., Ye, X. (2024). Unlocking artificial intelligence adoption in local governments: best practice lessons from real-world implementations. *Smart Cities*, *7(4),* pp. 1576-1625, https://doi.org/10.3390/smartcities7040064.

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PREMISES FOR IMPLEMENTING ECO-MARKETING IN PRO-ENVIRONMENTAL ENTERPRISE MANAGEMENT

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Purpose: The aim of the study is to fill the noted gap by deepening the understanding of the mandatory and optional rationales for implementing eco-marketing in pro-environmental enterprise management, identifying them and assessing the determinants of their implementation.
Design/Methodology/Approach: The research methods adopted in order to achieve the purpose include: in the theoretical part: literature studies; in the research part: research was conducted using a survey questionnaire, frequency analysis was conducted and Spearman's rank correlation were used to examine the strength and direction of the relationship among the variables studied.
Findings: The results obtained suggest that the relationship between the mandatory and the optional premises for implementing eco-marketing in pro-environmental enterprise management is becoming an important criterion for the success of pro-environmental attitudes in enterprise management.
Research Limitations/Implications: The research shows that the increase in the importance of legislation in the eco-marketing approach is accompanied by an increase in the fad for the use of eco measures, which underscores the need for a holistic approach that combines legal requirements with dynamic market trends. This opens up new avenues of research that can contribute to a better understanding of how to comprehensively integrate these premises into companies' pro-environmental activities.
Practical Implications: The results of the research indicating a strong relationship between the mandatory premises (laws) and the optional ones (fad for eco-activities), have important practical implications for enterprises, as they cannot only have an impact on strengthening the competitiveness of enterprises, by building a sustainable reputation in the market, but can also make it possible to minimize the risks arising from eco-marketing regulations.
Social Implications: The results of the research, which indicate a strong correlation between the mandatory and optional premises for implementing eco-marketing, have important implications for the society, as combining legislation with market trends can contribute to building a more environmentally conscious society, which translates into better environmental stewardship and increased transparency and trust in relations between businesses and customers.
Originality/Value: This article contributes to research on understanding the relationship between the mandatory and the optional premises for implementing eco-marketing in pro-environmental enterprise management. By focusing on a combination of mandatory legal

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standards and optional environmental initiatives, companies are responding to market expectations, building credibility and public trust. This in turn promotes the ideas of sustainability and environmental responsibility among the public.
Keywords: eco-marketing, enterprise management, sustainable enterprise development.

1. Introduction

In the face of dynamic change, one of the most important challenges of today's enterprises is the decision to select and implement appropriate strategic organizational responses to the changing conditions of the market environment. Managers make decisions in the respective areas of enterprise management, among which marketing plays an important role. Of particular importance in marketing activities is the pro-environmental orientation of company management (Miles, Munilla, 2013). Proper eco-marketing-oriented management requires, on the one hand, considering the existing mandatory regulations (Pandey, 2019), and on the other, the optional factors such as customer preferences (Kulikova, Kondratenko, 2024) and the prevailing fad for an ecological approach (Pastrana, Fajardo, 2024), should be taken into account. The diversity of views on eco-marketing in pro-environmental enterprise management is a result of differences in perspective and literature sources in this area (Journeault et al., 2016; Wang et al., 2019; Rodriguez et al., 2024). Therefore, since the primary challenge facing businesses in today's global economy is constant change (Hamel, 2007), the research interests in this study focus on the areas of eco-marketing that enable adaptation to changes in the business environment, taking into account both mandatory regulations, such as legislation, and optional factors, such as the fad for eco measures in business operations. Therefore, the research question is: Are there correlations between mandatory and optional premises for implementing eco-marketing in pro-environmental enterprise management? In order to acquire new knowledge on the premises for implementation of eco-marketing, the purpose of the study was to fill the noted gap by expanding the understanding of the mandatory and optional premises for implementing eco-marketing in pro-environmental enterprise management, identifying them and evaluating the conditions for their implementation.

The structure of the publication consists of three main parts in order to fulfill the stated purpose of the paper. Part one, the theoretical one, presents a conceptual framework for the key premises for eco-marketing in pro-environmental enterprise management based on a critical analysis of the subject literature (Delmas, Ong, 2023; Testa, Boiral, Iraldo, 2023). The second part discusses the methodology of the research procedure used for fulfilling the purpose. The third one presents the results of an empirical study on the mandatory and optional premises for implementing eco-marketing in pro-environmental enterprise management. The entire paper concludes with theoretical conclusions, along with practical implications, an evaluation of the research results and a recommendation for further research in this area.

2. A Conceptual Framework for the Key Premises for Eco-Marketing in Pro-Environmental Enterprise Management

An important variation of marketing in enterprise management is eco-marketing. It emerged within the concept of sustainable development, which forced companies to change their approach to business development (Banyte et al., 2010). The conventional strategic recommendations for enterprises include developmental activities which lead to resource depletion, degradation and environmental pollution (Khan et al., 2021). Therefore, it is important that enterprise management processes, in any sector, take into account the pro-environmental (Vazifehdoust, et al., 2013) approach. In this context, eco-marketing is becoming the distinguishing feature of the latest expectations in strategic management (Miles, Munilla, 2013).

Assuming that eco-marketing is defined as the offer and sale of products that are ecological and environmentally friendly, targeted at customers with a higher level of environmental awareness (Kronenberg, 2007), it is worth noting that both the process of production and sale of eco-products should also be less burdensome to the environment (Maksudunov, Avci, 2020). To interpret the implications of these assumptions for enterprises, it is necessary to associate them with the relationships occurring both between the mandatory and the optional premises for implementing eco-marketing in pro-environmental enterprise management (Lee et al., 2014). It should be noted that the mandatory and optional premises for the implementation of eco-marketing are two social factors that are contrasting elements in the development of a pro-environmental attitude to enterprise management (Paterson et al., 2022). The mandatory premises for implementation of eco-marketing are related to the institutional environment of enterprises which provides the legal framework (Rutkowska-Sowa, Poznański, 2022). Optional premises for implementing eco-marketing are related to the customers and their expectations, the financial possibilities of buying eco-products and the fad for pro-environmental behavior (Kautish, Sharma, 2020).

It can be concluded that the conceptualization of eco-marketing from the perspective of a pro-environmental approach to enterprise management addresses the issues of interdependence occurring in the area of changing customer needs and expectations and changes in the current legal regulations of sustainable development. This may cause companies to incur additional capital expenditures to upgrade their production, distribution and marketing operations (Wang et al., 2013). Hence, the pressure to increase efficiency and sales (Waddock, 2024), and the need to reduce rising costs, may lead companies to act falsely (Wiktor et al., 2020), or manipulate the environmental benefits of the products offered (Marquis, Qian, 2022; Orzeł, Wolniak, 2019). The presented premises for implementing eco-marketing, considered in the context of pro-environmental enterprise management, represent two opposing areas that modern marketing should take into account. The above arguments make it worthwhile to

consider further whether there are correlations between the contrasting mandatory and optional premises for implementing eco-marketing in pro-environmental enterprise management.

3. Materials and Methods

Given the complex nature of the studied phenomenon, the empirical research was carried out using a survey questionnaire, which is an effective data collection method for obtaining structured information from a large number of respondents. The survey was organized in order to gather respondents' answers to two questions. The first question was: "The eco-marketing approach in enterprise management is driven by legislation". The second question was: "The eco-marketing approach in enterprise management is a result of the fashion for using eco-measures". The survey was carried out using the Computer Assisted Telephone Interview (CATI) technique. Respondents were asked to provide a response that characterizes, as best as possible, the degree to which they agree or disagree with each statement, by selecting one of five values on a Likert scale, i.e. from 1 to 5.

The population of the surveyed enterprises consisted of 1,025 micro, small, medium and large enterprises. The vast majority of entities surveyed were micro enterprises. The classification data in the survey questionnaire included the following criteria for the surveyed companies: size of the company, profile of the company's activity, main products of the company, percentage of foreign capital, type of organizational and legal form of the company, position of the respondent, age, length of service, specialization of the company, period of activity in the market, receivables cycle, amount of revenue, scope of activity, profitability of the company.

The research procedure was divided into two main parts. In the first one, a frequency analysis was carried out to identify the mandatory and optional premises for implementation of eco-marketing in the pro-environmental enterprise management. Frequency analysis makes it possible to present the percentage share of responses in comparison with the entire survey data set. It is graphically presented in the charts. In the second part of the procedure, Spearman's rank correlation, which measures the strength and direction of the monotonic relationship between two variables was used for analyzing the relationship between the mandatory and optional premises for implementing eco-marketing in pro-environmental enterprise management. This coefficient assumes values in the range from -1 to 1 (the closer to 1 or -1, the stronger the relationship).

The search for an answer to the research question posed is an iterative process, so the conclusions will be generalized at the conceptual level. By comparing the main purpose of the research with the data collected from respondents, the validity of the research approach adopted was confirmed.

4. Results

In the first part of the empirical study, an analysis of the frequency of responses was conducted for two questions. As can be seen from the data presented in Figure 1, 40% of respondents declared that they completely agreed and agree with the statement that the eco-marketing approach in enterprise management is driven by legislation. Therefore, it can be concluded that in the surveyed companies, environmental regulations and applicable legal norms (e.g. on environmental protection, waste management, or emissions) exert pressure on the operation of the surveyed companies. According to respondents, legislation forces companies to implement a pro-environmental approach to management, both in operational functioning and in marketing communications.

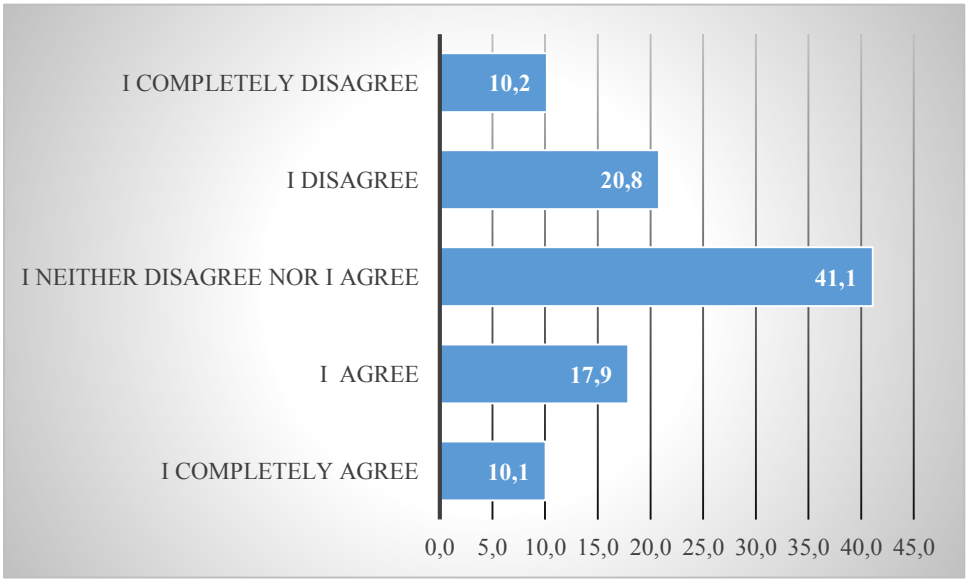

Figure 1. Structure of the surveyed enterprises according to the size of the enterprise.

Source: Own study based on conducted research.

The survey presented in Table 1 shows that 28% of respondents completely disagree or disagree that in their enterprise, the eco-marketing approach to enterprise management is driven by legislation. This may mean that these respondents may see eco-marketing as a result of internal corporate strategies, stemming from the desire to build an image and respond to customer expectations and the desire to stand out in the market. Perhaps in their view, eco-activities are a voluntary element of competitive strategy, rather than directly imposed by law.

In contrast, 41% of respondents said they did not have an opinion on whether an eco-marketing approach in enterprise management is driven by legislation. This may mean that this group of respondents has ambiguous knowledge about the extent to which the law influences the eco-marketing approach. This may be due to the belief that legislation is one of many factors, along with market trends, consumer pressure and adopted strategy, that collectively shape eco activities, making it difficult for these respondents to clearly consider legislation to

have a dominant role. Figure 2 shows respondents' answers to the question about the connection between the eco-marketing approach and the fad for using eco measures.

It can be concluded based on Figure 2 that more than 41% of the respondents declared that they completely agreed or agreed with the statement that in their enterprise the eco-marketing approach in enterprise management resulted from the fad for eco measures. The surveyed companies perceive eco-marketing as a fad, suggesting that eco activities are aimed at improving image or may be a response to market expectations. More than 14% of respondents declared that they completely disagreed or disagreed with the above statement, which may mean that this group of respondents rejects the thesis that eco-marketing is only due to the fad for eco measures. This may be due to the fact that these respondents believe that environmental activities in companies are dictated by other motives, such as concern for the environment, a response to regulations, or growing consumer awareness. Therefore, for this group of respondents, eco-marketing may be part of strategic management, not just a fad.

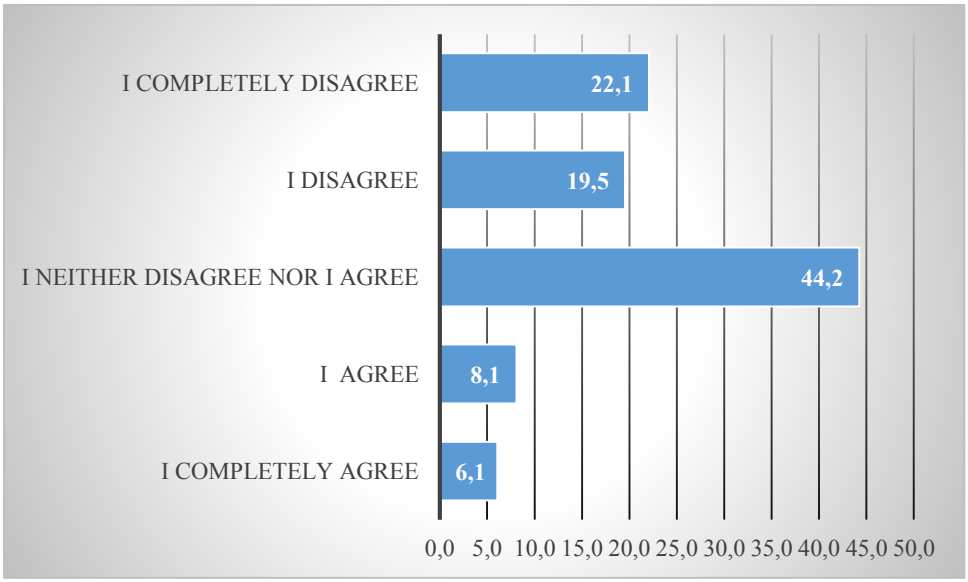

Figure 2. Structure of the surveyed enterprises according to the size of the enterprise.
Source: Own study based on conducted research.

It should be noted that 44.2% of respondents said they were adopting a neutral stance on whether eco-marketing only results from a fad for eco measures. This may mean that this group of respondents sees in eco-marketing both elements, i.e. the fad and the rational strategy, making it difficult for them to clearly assess the dominant motivation. It is also possible that they lack the sufficient knowledge or convincing evidence to classify eco-marketing as merely a fad.

In the second part of the empirical study, in order to determine the value of the Spearman's rank correlation coefficient for the two questions, the calculation procedure treated the five response categories on the Likert scale as pairs of observations, where for each category the percentage representation of the responses for the first and second questions was assumed. Ranks were assigned for each variable based on percentages. The results of the calculations are presented in Table 1.

Table 1.
Spearman's rank correlation coefficient between respondents' answers to questions about the evaluation of the interrelationships between the mandatory and optional premises for the implementation of eco-marketing in pro-environmental enterprise management

List	The eco-marketing approach in enterprise management is driven by legislation
The eco-marketing approach in enterprise management is the result of the fad for eco-activities.	0.7***

Note: *** statistically significant result at $\alpha = 0.01$.

As a result of the calculations, the Spearman's rank correlation coefficient for the two questions is 0.7. This implies a strong positive correlation, indicating that the categories of both responses to the questions posed to respondents are ordered in a very similar way. It is worth noting that aggregate data was used in the calculations, and this result indicates that respondents have a relatively similar assessment of the two aspects of eco-marketing studied.

5. Discussion

When considering the premises for implementing eco-marketing in pro-environmental enterprise management, it should be noted that respondents' answers are characterized by certain paradoxes. First, the paradox emerges in the answers given by respondents between the obligatory and the optional. On the one hand, some respondents emphasize the obligatory nature, which stems from the law, suggesting that the surveyed companies operate within a well-defined legal framework. On the other hand, a significant group of respondents believe that eco-marketing results from optional marketing decisions and activities. This indicates a contradiction between seeing corporate actions as forced, and interpreting them as part of a competitive strategy. Second, there is the paradox about knowledge and uncertainty. The high number of neutral responses may indicate a lack of sufficient knowledge or clarity in assessing the impact of regulations on companies' operations. The paradox is that despite the existence of specific legal regulations, many respondents cannot clearly assess whether the law is the main factor that affects eco-marketing. This may be due to ambiguities in the interpretation of regulations or differences in respondents' work experience. The third paradox refers to sectoral and individual differences, as responses may reflect the peculiarities of companies operating in different sectors, where legal regulations are very important, while in others market trends and consumer pressure are key. This divergence of interpretation creates a paradox where one and the same phenomenon, such as eco-marketing, can be seen both as imposed by law and as a result of internal company decisions.

Examining the results of the surveys conducted, it is also noted that there is a contradiction between fad and strategy in the answers given by respondents. On the one hand, according to respondents surveyed (36.8%), eco-marketing is a fad. On the other, a significant group of

respondents (20%) believe that this is not just a fad, but results from other, more rational premises. This dichotomy suggests that there is a conflict in the perception of eco-marketing between a superficial vision and a deeper, strategic approach.

In addition, it is worth noting the dominance of neutrality declared by the respondents surveyed. The largest share of respondents (43.3%) do not clearly take sides in addressing the question of whether the eco-marketing approach in enterprise management is due to the fad for using eco-measures. This may indicate that the boundaries between a fad and an authentic strategy are unclear to many respondents, or that respondents lack sufficient information to make a definitive judgment. Such neutrality may reflect the complexity and multifaceted character of the issue under consideration, where both trend pressures and long-term strategies, can coexist. What is more, respondents' interpretation of the phenomenon of eco-marketing itself may also result in contradictions. The paradox here stems from the fact that companies can present their eco-marketing activities as part of their social responsibility, while at the same time they can use this narrative as a fashionable way to improve their image. This may mean that respondents recognize this duality, and on the one hand confirm, in the survey results, a genuine concern for the environment, while on the other some respondents use the eco trend for marketing purposes.

The study's results (a strong correlation, $r = 0.7$) confirm the thesis of Miles and Munilla (2013) regarding the complementarity of regulatory and market drivers in eco-marketing. Moreover, this finding supports Paterson's (2022) "dual-pressure" concept, according to which institutions and customers constitute a joint source of motivation. It is also noteworthy that some respondents treat fashion trends as the basis for action, in line with the observations of Pastrana and Fajardo (2024) on trend-driven fashion marketing.

At the same time, several nuances emerge in relation to the theoretical frameworks discussed in this paper. The high proportion of neutral responses challenges the unequivocal claim of Lee et al. (2014) that pro-environmental attitudes have stable, clearly defined determinants. Likewise, the absence of significant sectoral differences does not confirm Journeault et al.'s (2016) assertion that the strength of regulatory influence varies by industry.

6. Conclusions and Summary

Research on identification of the premises for eco-marketing and the evaluation of the conditions for its implementation in pro-environmental enterprise management is currently emerging in the form that deserves to be called sustainable. Therefore, clarification of the relationship between the mandatory premises, resulting from the law, and optional ones, being a consequence of the fad for ecological activities, for the implementation of eco-marketing in

pro-environmental enterprise management, is becoming an important criterion for the success of the pro-environmental attitude in enterprise management.

An analysis of the results of the empirical survey showed that the responses of the respondents substantiated the differences in the perception of the premises for implementing eco-marketing. On the one hand, legislation is seen as a mandatory factor, forcing activity of environmental nature. On the other hand, eco-marketing appears to be an optional component of companies' marketing strategy. Moreover, it is worth noting that the significant number of neutral responses may indicate ambiguity and complexity of the relationship between the mandatory and optional premises for implementing eco-marketing in pro-environmental enterprise management. Such paradoxes may mean that companies' eco-marketing decisions are the result of the interaction of many factors.

The survey shows that respondents' perceptions of eco-marketing are multifaceted. Some of those surveyed view eco-marketing as a trendy element of marketing strategy, used mainly for image purposes. However, another group of respondents sees it as an element stemming from regulations. The highest number of neutral responses suggests that for many respondents, the boundaries between a fad and strategic environmental responsibility are blurred, reflecting the complexity of modern business operations. Such a paradox illustrates that eco-marketing combines both managerial aspects and those driven by social pressure and market trends. In addition, it is worth noting that Spearman's rank correlation coefficient for both questions shows a strong positive relationship. Thus, it can be assumed that the increase in the importance of legislation in the eco-marketing approach is accompanied by an increase in the fashion for the use of eco measures, which is an important premise for the implementation of eco-marketing in pro-environmental enterprise management.

When considering the implementation of specific managerial solutions or frameworks to address identified tensions, one option worth exploring is a “zero-neutrality” policy, which obliges employees to take a clear position (a Delphi technique) and thereby reduces cognitive ambivalence. Another possible approach is the 4E Process (Explore–Embed–Evaluate–Expose). Explore involves scanning the legal environment and ESG trends; Embed concerns integrating the relevant requirements into KPIs and budgets; Evaluate covers the monitoring of metrics such as CO_2 per product or eco-NPS and arranging independent audits; Expose focuses on transparent reporting and the declaration of compliance with GRI 2021 and CSRD. Naturally, the range of solutions available in this area is broad, and any final choice should be tailored to the specific needs and expectations of each enterprise.

A clear implication from the research is that the effectiveness of pro-environmental enterprise management activities should integrate both the mandatory and the optional premises for implementing eco-marketing. Companies that combine existing legal standards with market trends and customer expectations, can achieve better results. In practice, this means that managers should develop comprehensive strategies with regulations as the foundation, which should be flexibly supplemented with innovative approaches. Moreover, the relationship

between the mandatory and optional premises for the implementation of eco-marketing requires companies to constantly monitor the environment and to adapt, which promotes innovation and the ability to effectively respond to dynamic changes in the market. Transparent compliance with the law combined with innovative pro-environmental measures, helps build a credible corporate image, which can translate into increased trust from customers, investors and other stakeholders. This statement is an expression of optimism, despite the awareness of occurrence of greenwashing and manipulation in the field of eco-marketing. The breakthrough character of the presented research results is related to new research assumptions in the field of eco-marketing, which can form the basis for formulating more precise and effective regulations that will support pro-environmental activities, not only in the business sector.

The multifaceted nature of the issue of eco-marketing in pro-environmental enterprise management and the interdisciplinary nature of the considerations have made the paper present only the selected premises for the implementation of eco-marketing. Some of the considerations are general which, on the one hand, helps to emphasize the complexity of the issues involved, but on the other inspires further research and exploration in this area. Further research in the field of eco-marketing should focus on identifying potential causal pathways between these premises and the effectiveness of eco-marketing implementation in companies.

References

1. Banyte, J., Brazioniene, L., Gadeikiene, A. (2010). Expression of green marketing developing the conception of corporate social responsibility. *Inžinerinė ekonomika*, *21*(5), 550-560.
2. Delmas, M., Ong, R. (2023). Mandatory ESG Disclosure and the Decline of Symbolic Environmentalism. *Strategic Management Journal, 44(5),* 987-1012. doi:10.1002/smj.3388
3. Hair, J.F. et al. (2014). *Multivariate Data Analysis*. Upper Saddle: Pearson Education, 129, pp. 282-288.
4. Hamel, G. (2007). *Future of management.* Boston, Massachusetts: Harvard Business School Press.
5. Journeault, M., De Rongé, Y., Henri, J.F. (2016). Levers of eco-control and competitive environmental strategy. *The British accounting review*, *48*(3), 316-340,
6. Kautish, P., Sharma, R. (2020). Determinants of pro- environmental behavior and environmentally conscious consumer behavior: An empirical investigation from emerging market. *Business Strategy & Development*, *3*(1), 112-127.
7. Khan, N., Jhariya, MK, Raj, A., Banerjee, A., Meena, R.S. (2021). Ekoprojektowanie dla zrównoważonego rozwoju. *Ekologiczna intensyfikacja zasobów naturalnych dla zrównoważonego rolnictwa*, 565-595.

8. Kronenberg, J. (2007). Ekomarketing i jego instrument. *Acta Universitatis Lodziensis Folia Oeconomica, 204,*p. 93.
9. Kulikova, E., Kondratenko, I. (2024). Eco-branding and consumer behavior: innovative marketing strategies in ecology and environmental sciences. *E3S Web of Conferences, Vol. 541*. EDP Sciences, p. 04005.
10. Lee, Y.K., Kim, S., Kim, M.S., Choi, J.G. (2014). Antecedents and interrelationships of three types of pro-environmental behavior. *Journal of Business Research*, *67*(10), 2097-2105.
11. Maksudunov, A., Avci, M. 2020. The Color of the Future in Marketing is Green. Contemporary Issues in Strategic Marketing. *MDPI, 15(3),* 225-254. ISSN 2071-1050. doi:10.26650/B/SS05.2020.002.07
12. Marquis, C., Qian, C. (2022). Corporate Greenwashing: A Review and Research Agenda. *Academy of Management Annals*, *16(1),* 1-47. doi: 10.5465/annals.2020.0059
13. Miles, M., Munilla, L.S. (2013). The eco-marketing orientation: an emerging business philosophy. In: *Environmental Marketing* (pp. 23-36). Routledge.
14. Orzeł, B., Wolniak, R. (2019). Overview of Greenwashing Methods and Tools Used in Polish and World Enterprises. *Scientific Papers of Silesian University of Technology, Organization and Management Series, no*. *138*, pp. 211-219.
15. Pandey, S. (2019). Eco marketing and innovations in developing sustainable and green environmental standards. *International Journal of Business Innovation and Research*, *18*(3), 293-306.
16. Pastrana, L.E.C., Fajardo, J. (2024). Green Marketing Strategies in Sustainable Fashion Business Models. In: *Sustainability, Stakeholders and Marketing in the Textile Sector: Conceptual and Practical Cases for the Americas* (pp. 109-129). Singapore: Springer Nature Singapore.
17. Paterson, F., Baranova, P., Gallotta, B. (2022). Towards a conceptual framework of enterprise support for pro-environmental small and medium-sized enterprises: A contextualised review of diverse knowledge domains. *Local Economy*, *37(3),* 142-168.
18. Rodriguez, A.I.P., Licea, J.P.B., Chavez, Y.O. (2024). Ecomarketing. Green Jobs: An Opportunity for Women. *Opuntia Brava*, *16*, 114.
19. Rutkowska-Sowa, M., Poznański, P. (2022). Legal aspects of green-branding. *Eastern European Journal of Transnational Relations*, *6*(2), 57-69.
20. Suchecki, B. (ed.) (2010). *Ekonometria przestrzenna. Metody i modele analizy danych przestrzennych*. Warszawa: C.H. Beck.
21. Testa, F., Boiral, O., Iraldo, F. (2023). From Eco-labels to ESG Ratings: How Signals Shape Stakeholder Trust. *Business Strategy and the Environment*, *32(8),* 4110-4128. doi: 10.1002/bse.3378

22. Vazifehdoust, H., Taleghani, M., Esmaeilpour, F., Nazari, K., Khadang, M. (2013). Purchasing green to become greener: Factors influence consumers' green purchasing behavior. *Management Science Letters*, *3*(9), 2489-2500.
23. Waddock, S. (2024). The ESG Paradox: Managing Pressures and Performance. *Organization & Environment*, *37(1),* 84-107. doi: 10.1177/10860266231168905
24. Wang, D.T., Gu, F.F., Dong, M.C. (2013). Observer effects of punishment in a distribution network. *Journal of marketing Research, Vol. 50.*
25. Wang, Z., Wang, L. (2019). Research on Ecological Marketing Strategy of Modern Enterprises-Take MI Company as an Example. *Ekoloji Dergisi, 107*.
26. Wiktor, J.W., Sanak-Kosmowska, K. (2020). Organisational Aspects of Research on Manipulation in Advertising in an International Environment. *Przegląd Organizacji, no. 10,* pp. 5-12.

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BUSINESS MODEL CONVERSION IN THE CHANGING CONDITIONS OF BUILDING THE MARKET POSITION OF ENTERPRISES

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Purpose: The aim of the study is to understand the business model conversion in enterprises cooperating with market partners by examining the relationship between the implementation of innovative organizational solutions and enhancement of customer and market knowledge.
Design/methodology/approach: The empirical research was carried out on the basis of subject literature studies and statistical analysis using Kendall's rank correlation and Kruskal-Wallis test. The relationship between the implementation of innovative organizational solutions and enhancement of customer and market knowledge in order to understand the business model conversion in enterprises cooperating with market partners was taken into consideration.
Findings: The research results suggest that cooperation with market partners is conducive to the business model conversion, which is accompanied by the implementation of innovative organizational solutions and enhancement of customer and market knowledge.
Research limitations/implications: The presented research provides reliable information only with certain assumptions and has some limitations that affect the possibility of their empirical application. The limitation of the results obtained is the fact that the research does not take into account macroeconomic, legal, demographic and social factors that may affect the business model conversion in enterprises cooperating with market partners.
Practical implications: Strong positive relationships between the implementation of innovative organizational solutions and enhancement of customer and market knowledge is important for the business model conversion and management of enterprises cooperating with market partners.
Social implications: The results of the conducted research can have a positive impact on society, because better understanding of customers leads to the creation of products and services better adjusted to real social needs, which can improve the quality of life of consumers and support the development of more inclusive labor markets.
Originality/value: The conducted research sheds new light on the perception and understanding of the business model conversion in micro and small enterprises. Thanks to the business model conversion carried out based on innovative operation and customer and market knowledge, micro and small enterprises can respond more effectively to market trends.
Keywords: enterprise management, business model, innovation, customer and market knowledge.
Category of the paper: Research paper.

1. Introduction

In a dynamic market environment, innovation and knowledge have become the conditions for survival and development of modern enterprises. Building partnership ecosystems, through strategic alliances, suppliers' networks, cooperation with market partners, allows for responding faster to changes in customer preferences or technological progress. Moreover, interorganizational cooperation becomes a response to competitive pressure. Therefore, enterprises that combine organizational forces may adapt their business models faster to new conditions and create innovative solutions in the conducted business activities. It is worth noting that the market environment of the business model affects both exogenous and endogenous variables, making the business model convert under the influence of changes in customer needs and preferences in terms of value proposition. (Gebauer et al., 2020) This means that, in the era of the knowledge-based economy, innovative solutions and customer and market knowledge become the main factors of enterprise development.

It is important to distinguish between two distinct concepts: the innovative business model and business-model conversion. An innovative business model involves creating an entirely new logic of operation to generate above-standard value, whereas business-model conversion consists of modifying the existing logic to remain aligned with a dynamic environment (Chesbrough, 2010). The key differences lie in the impulse behind the change, the level of novelty, the scope of the transformation, and the roles of partnerships and knowledge. Understanding these dimensions enables researchers and practitioners to select more appropriate tools and success metrics, depending on whether a firm faces the challenge of innovation or of business-model conversion (Saebi et al., 2017).

The particular importance of the factors is noticed in the activities of micro and small enterprises. Micro and small enterprises, operating in cooperation with market partners, more and more frequently notice that the manner of organizing business activities, taking into account the implementation of innovative organizational solutions, has a key impact on their ability to learn about customers and the market and, consequently, on the conversion of their business model. In this approach, the key research question is: “How do the relationships between the implementation of innovative organizational solutions and enhancement of customer and market knowledge shape business model conversions in enterprises collaborating with market partners?” As a consequence of this question, the objective of the study was to understand the conversion of the business model in enterprises cooperating with market partners by examining the relationships between the implementation of innovative organizational solutions and enhancement of customer and market knowledge. This research objective corresponds with the H1 hypothesis that: in enterprises, cooperation with market partners is conducive to the conversion of the company’s business model, which is accompanied by the implementation of innovative organizational solutions (A1) and enhancement of customer and market knowledge

(A2). The research methods used to accomplish the objective are critical analysis of literature and statistical analysis using Kendall's rank correlation and Kruskal-Wallis test.

The problem of the business model conversion in changing business conditions, presented in foreign and domestic literature on the subject, is fragmentary and dispersed. Therefore, the considerations discussed are relevant and up-to-date due to the possibility of capturing the dynamics of changes in the business model in the process of gaining and maintaining a competitive advantage.

1.1. The company's business model and its conversion

The business model is a strategic management tool, which was created as a result of permanent changes occurring in the endogenous and exogenous environment of enterprises. In this context, the task of the business model becomes to explain a specific field of reality that helps to realize that reality by providing specific applications (Dubosson-Torbay et al., 2002) and achieving the intended business objectives of enterprises. The effect of implementing the business model should be knowledge built on the observation of socio-economic phenomena (Tong et al., 2022), which is reflected in the effectiveness of intellectual capital use, which is the company's root system (Gebauer et al., 2020). Combining core components and key abilities with the proper configuration of the company's resources in the business model allows for creating a unique offer considering innovative product, process and management solutions. However, providing the framework for the implementation of new, innovative solutions in the business model and its conversion requires possessing up-to-date information (Prusak, Davenport, 2013), particularly in the field of virtualization of economic reality (Łęgowik-Świącik, 2023). This means that the business model should take into account the scope of the company's activities and the specificity of the sector in which the company operates, and to direct processes and activities in such a way as to enable the enterprise to maintain and increase its competitive advantage on the market.

In this context, the business model becomes a value accelerator that accelerates value creation processes, enabling the generation of revenue stream considering the cost structure and price policy adopted (Abolfathi et al., 2022). This means that the business model should implement value accelerators of an active nature. Thus, formulating the directions of operation for the business model conversion should be accelerated by those value accelerators (Sobko, 2015) which hold the potential to achieve a competitive advantage. The key value accelerators in the business model are innovation and intellectual capital (Davenport et al., 2009), which take into account the scope of activities and key abilities as well as configuration of resources, (Lange, Johnston, 2020) which allow the creation of a unique offer, assuming an effective price policy.

Enterprises in the early stages of development should convert the business model to create a new value. This means that these enterprises, when entering cooperation with market partners, should implement innovation that influences attitudes of innovative stakeholders (Galvão et al.,

2023). Therefore, the business model conversion includes, not only assessing the options of using the individual components of this model to create value in terms of ex post, but also conducting cognitive activities, which enable indicating the relationships between individual components of the business model in terms of ex modernum and ex ante.

In the case of enterprises characterized by a state of relative balance in terms of their competitive position, the business model conversion should be complemented by interactive value accelerators which lead to achieving an increase in the market share in the long-term perspective (Kovacs, 2023). However, in the short-term perspective, the company's value fluctuates, which is why the business model should also particularly take into account value accelerators such as: core components (Mohammadi, Sakhteh, 2023), revenue streams, cost structure, activities, processes, the specificity of the sector, and extend cooperation with market partners based on network principles.

In the case of enterprises characterized by a decrease in the company's competitive position (Jung, Kim, 2022), and thus the outflow of customers and a decrease in profitability, the business model conversion should be complemented by reactive value accelerators which will allow the scope of activities to be adapted to the changing environment. This will enable, on the one hand, acquiring new revenue streams by implementing innovative solutions (Slywotzky et al., 2007), and on the other, allow for using selected information and knowledge (Slywotzky, Drzik, 2005) as well as cooperation based on network principles, including virtual markets.

To sum up, it is worth emphasizing that value accelerators in the business model conversion penetrate individual stages of value migration, complement them, but they are not identical. The presented value accelerators do not constitute a closed list. However, considering the fact that each enterprise may be in one of the three stages of value migration (Noviaristanti et al., 2024), it should individually select accelerators that will allow the acceleration of the value creation process. The choice depends on the manager's decision, however, the functioning of the company in changing conditions for building the market position of enterprises, determines the need for flexible configuration of value accelerators, which in turn results in business model conversions.

2. Methods

To understand the business model conversion in enterprises cooperating with market partners and to examine the relationships between the implementation of innovative organizational solutions and enhancement of customer and market knowledge, the empirical research was carried out based on the data obtained with the survey questionnaire using the CATI method. The questionnaire was validated through a pilot test conducted on a sample of

20 Polish enterprises. This pilot made it possible to carry out a preliminary assessment of the questionnaire under conditions comparable to the main study. Its principal advantage lies in the early identification of potential issues and their correction before the full-scale research is launched (Willis, 2016). The statements in the survey questionnaire were evaluated by the respondents on a five-point Likert scale (from 1 – "totally disagree" to 5 – "totally agree"). The respondents were the senior management staff of the surveyed enterprises. Of the 349 enterprises included in the research sample, the dominant activity profile was service activities - 72.8% (followed by production 21.2%, and trade 6%). Most, since 68.5% of the surveyed enterprises, are micro enterprises (followed by small - 12.0%, large - 10.9%, and medium - 8.6%). Considering the territorial scope of the conducted business, the activities with a national scope dominated - 45.8% (followed by global - 14.1%, European - 10.3%, and local - 29.8%). The research sample included enterprises operating in the private sector.

The empirical part of the research was divided into two fundamental parts. In the first part, the survey frequency analysis was conducted. This analysis allows the examination of the distribution of responses received and an orderly statement of observations in each category of responses (Corder, Foreman, 2009). Frequency analysis is a one-dimensional analysis describing the distribution of a single variable (Vogel et al., 2020). It is a tool for quantitative data analysis in survey studies and is a starting point for further statistical analyzes.

In the second part of the empirical research, an in-depth analysis was carried out using Kendall's rank correlation coefficient and Kruskal-Wallis test. Kendall's rank correlation is calculated based on comparing observation ranks for both variables. On this basis, the tau (τ) value is determined, which is a relative difference between the percentage of concordant and discordant pairs. This coefficient takes values from -1 to 1, where $\tau = 1$ indicates perfect concordance of ranks, $\tau = -1$ denotes a perfectly reversed order, and $\tau = 0$ suggests no significant monotonic relationship between the variables. The correlation analysis was to make it possible to achieve the intended objective — understanding the business model conversion in enterprises cooperating with market partners by examining the relationship between the implementation of innovative organizational solutions and enhancement of customer and market knowledge.

3. Results

In the first part of the empirical research, it was analyzed what proportion of the respondents agreed (responses on a five-point Likert scale) with the statements concerning collaboration with market partners, which is conductive to the business model conversion, thus enabling the implementation of innovative organizational solutions.

Based on the data presented in Table 1, it can be noted that almost 82% of the respondents agree, or totally agree with the statement that cooperation with market partners is conducive to the business model conversion and allows the implementation of innovative organizational solutions. This means that, according to this group of respondents, the design of new solutions together with market partners (e.g. within working groups, consortia, clusters) promotes creativity and groundbreaking innovation. According to the respondents, the active participation of partners in the process of innovation improves generating and implementing new organizational concepts. Cooperation with market partners, due to the effect of synergy, is conductive to the business model conversion by introducing new distribution channels, customer segments, or manufacturing methods elaborated along with a partner. Figure 1 shows the frequency of the respondents' answers to the question.

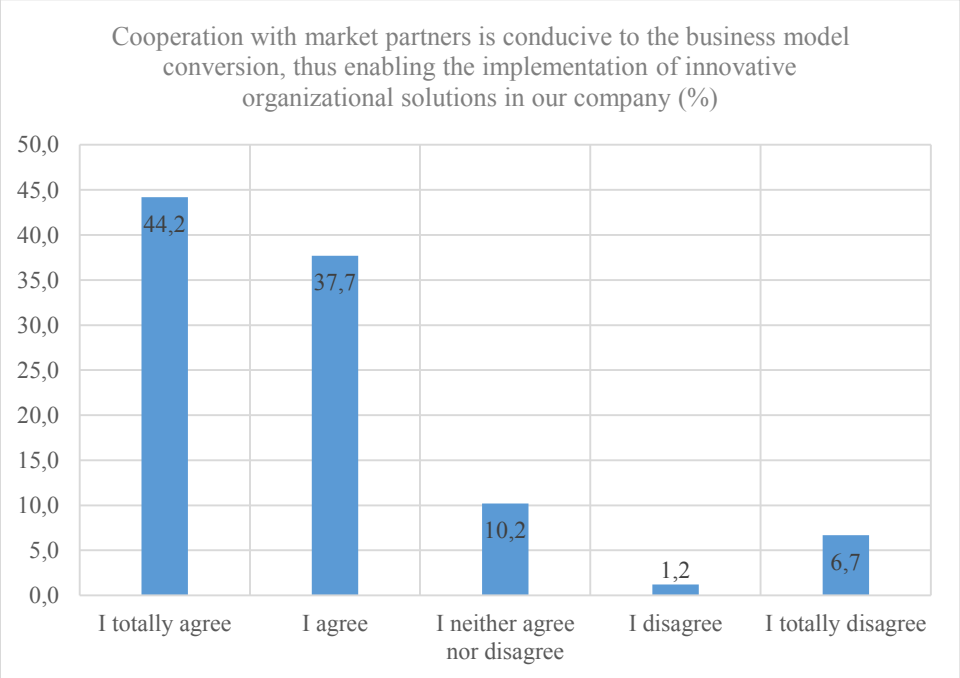

Figure 1. In enterprises, cooperation with market partners is conducive to the business model conversion, which is accompanied by the implementation of innovative organizational solutions.

Source: Own study.

It is worth noting that about 8% of managers do not agree with the statement in question, and 10% are neutral. This may result from a lack of direct experience in terms of cooperation with market partners, which is favorable for changes in the business model, which means that this group of respondents does not see the value of cooperation. Another reason for this may be a low level of trust or fear that cooperation may pose a risk associated with the disclosure of trade secrets, which translates into the skepticism of this group of respondents. In addition, it is worth noting that managers may not notice the need to convert the business model as a result of cooperation with market partners. These factors can explain why these respondents are not in favor of the approach of most respondents.

In the subsequent part of the empirical research, the frequency analysis was carried out concerning the respondents' answers to the statement relating to cooperation with market partners, which promotes the business model conversion, thus enabling enhancement of customer and market knowledge. Figure 2 shows the frequency of the respondents' answers to the second question.

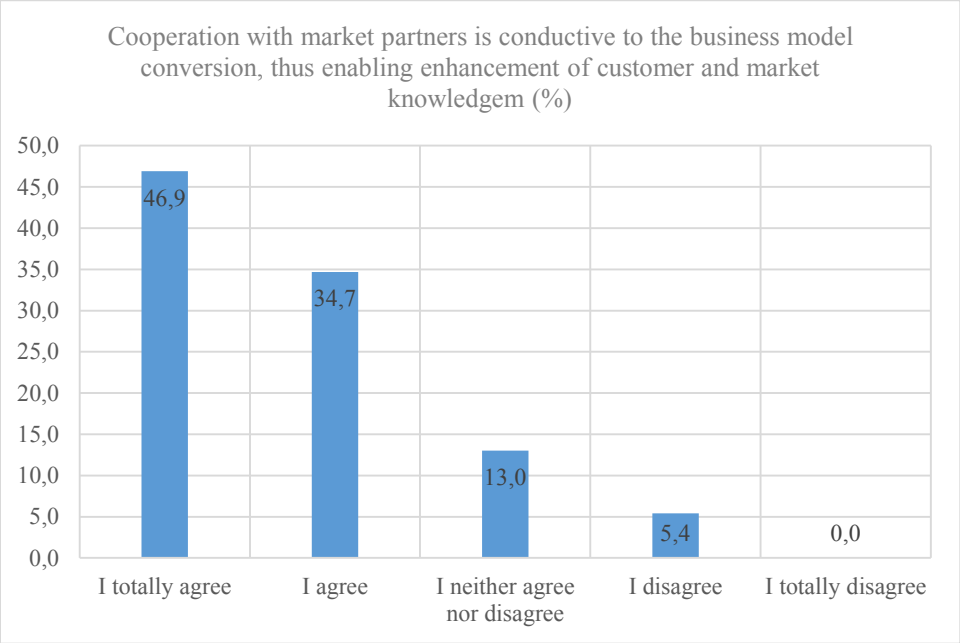

Figure 2. In enterprises, cooperation with market partners is conductive to the business model conversion, thus enabling enhancement of customer and market knowledge.

Source: Own study.

Based on the research results presented in Figure 2, it can be noted that almost 82% of the respondents agree or totally agree with the statement that cooperation with market partners is conducive to changes in the company's business model, which contribute to enhancement of customer and market knowledge. Such a significant advantage of positive answers may indicate a strong conviction of the respondents that through interactions with partners the company may create and offer value, since market partners can bring additional competences, technologies or information, which prompts the business model conversion to generate added value. The obtained research results may mean that the enterprises examined, thanks to partnerships, expand the resources of market and customer knowledge. They may realize this in joint development projects, in which partners share knowledge of customer preferences or effectiveness of market service methods, which allows their adaptation. Exchange of knowledge promotes organizational learning and can lead to improvements in the business model in line with customer expectations.

Interestingly, only 5.4% of the respondents do not agree with the statement in question (0% total lack of consent), and the remaining 13.0% retained a neutral attitude. Such a distribution may suggest that a small group of managers does not see the benefits of cooperation or encountered problems associated with it. Such a situation may occur if a market

partnership lacks trust or knowledge sharing mechanisms. Moreover, in the case of micro-enterprises, partnership may be imposed (e.g. by a stronger partner) and perceived as a limitation of decision-making freedom, which may result in skepticism in the field of actual expansion of market knowledge. Another reason for disagreement may be the conviction that it is mainly own business activities and unique vision of the company that shape its business model, and the partners play a secondary role. However, the fact that no respondent chose the extreme negative answer suggests that even skeptics admit that the arguments for cooperation have the merits, although they can assess them as less important in their context.

The neutrality of the respondents (13%) in relation to the statement that cooperation with market partners is conducive to changes in the company's business model, which enhances customer and market knowledge, may result from caution or lack of unambiguous experience. Some respondents may not know if their company's cooperation with market partners translates into better customer and market knowledge. They may operate in industries where internal knowledge (e.g. own research or direct market research) is valued more than information from partners, hence their hesitation may also result from this fact.

The last part of the empirical research consists in conducting an in-depth analysis, based on the studies of Kendall's rank correlation and Kruskal-Wallis test. Correlation analysis allows for looking at the relationships between the implementation of innovative organizational solutions and enhancement of customer and market knowledge, which will enable understanding the business model conversion in enterprises cooperating with market partners. The relationships under research were verified at the significance level of 0.05. The results are presented in Table 1.

Table 1.
Kendall's rank correlation coefficient between the respondents' answers to the questions about the assessment of benefits of cooperation with market partners, which promotes changes in the company's business model thus enabling the implementation of innovative organizational solutions (A1) and which is accompanied by enhancement of customer and market knowledge (A2)

In enterprises, cooperation with market partners is conductive to the business model conversion, which is accompanied by:		Implementation of innovative organizational solutions (A1)
1	enhancement of customer and market knowledge (A2)	0.81***

Notice: *** statistically significant result at $\alpha = 0.01$; ** – at $\alpha = 0.05$.

Own study based on the conducted research.

The $\tau = 0.8$ coefficient in Kendall's rank correlation indicates a very strong positive relationship (Table 1). This means that the higher the response scale in one question the higher it is in the other. The relationship is systematic, which suggests that the respondents evaluate the impact of cooperation with market partners on organizational innovation and enhancement of customer and market knowledge in a relatively consistent manner. The result of Kruskal-Wallis test of $H \approx 0.03$ (with 1 degree of freedom) is very low, which indicates no statistically significant differences between the response distributions for the two questions. This means that the response distributions for both questions are very similar.

4. Discussion

Considering the results of the conducted research, it is worth noting that such a high level of agreement indicates that the surveyed enterprises, regardless of the size (large, medium, small and micro), undertake pro-innovative activities in terms of organizational activities that emphasize openness to external knowledge and cooperation. A contemporary approach to innovation assumes (Amit, Zott, 2012) that enterprises achieve better innovative results when they open their borders and cooperate with partners from the environment: suppliers, customers, other entities. The conducted research shows that managers share this approach. The research results indicate the conviction that cooperation with market partners becomes a lever of changes and improvements in the business model of the surveyed enterprises. This attitude is characteristic of a pro-innovative organizational culture, where the management staff actively looks for new solutions and encourages learning from other entities, instead of relying only on internal ideas.

The research conducted using Kendall's rank correlation coefficient shows a strong positive correlation ($\tau = 0.8$), which indicates that the respondents assess the aspect of cooperation with market partners, both due to the possibility of implementing innovative organizational solutions as well as in terms of enhancement of customer and market knowledge in a similar manner. The Kruskal-Wallis test result ($H \approx 0.03$) confirms that the response structure is similar for both questions, therefore, it can be assumed that the results of the analysis confirm the consistency and systematicity of assessing the impact of cooperation with market partners on both assessed aspects of the company's functioning.

In the literature on the subject, it is emphasized that external relations are conducive to generating new ideas, improving innovation processes and generating new knowledge (Chan Kim, Mauborgne, 2005). This means that cooperation within inter-organizational networks facilitates the development of new products, co-creating innovation and may enhance customer and market knowledge, which translates into increased business performance. Knowledge of the customer and the market and innovation acquired in this way translate into the ability to convert the business model. Companies can use this knowledge to identify new customer segments, access channels or ways of generating revenue and redesign their business model accordingly. The conducted research sheds new light on the perception and understanding of the business model conversion in micro and small enterprises. The conversion of the business model based on innovation and knowledge of the customer and the market enables micro and small enterprises to respond more effectively to market trends and needs, thereby increasing their competitiveness.

The clear implication of the research is that cooperation with market partners promotes the business model conversion, which is accompanied by the implementation of innovative organizational solutions and enhanced customer and market knowledge. The above results are

statistically significant, which supports the H1 hypothesis. Establishing collaboration, whether in the form of a strategic alliance, a technology partnership or a joint project with a customer, can force a transformation in the way the company creates and offers value. Therefore, management oriented towards innovation and acquiring customer and market knowledge should be considered as an opportunity for development and competitiveness.

5. Conclusions and summary

Summing up the conducted research, it is worth noting that the business model conversion requires coordination and precision in defining all factors shaping both the proposition of a new value for the customer and the company's future development based on innovation. Therefore, the comprehensive identification, analysis and diagnosis of factors shaping the business model conversion is necessary due to the need to obtain selected information about external and internal conditions of this conversion.

The result of Kendall rank correlation coefficient is ($\tau = 0.8$), which indicates a very strong positive relationship between the responses to both statements. This means that the implementation of innovative organizational solutions (A1) is generally accompanied by enhancement of customer and market knowledge (A2), which allows the understanding of the business model conversion in enterprises cooperating with market partners. Considering the synergy between the examined statements, it should be noted that factors such as innovative organizational solutions and enhancement of customer and market knowledge contribute to the business model conversion, which is a theoretical contribution, that extends the learning of the concept of business models. The connection between organizational innovation, market knowledge and business model conversion is important for modern enterprise management processes, because until recently these aspects were considered separately. Traditionally, product or technological innovation was the focus of attention, whereas the role of organizational changes and learning from customers in shaping the business model was ignored. Currently, however, the latest research emphasizes that orientation towards customer knowledge is a key factor that drives the business model conversion (Fidel et al., 2018; Bocquet et al., 2020).

The results of the conducted research shed new light on the perception and understanding of the business model conversion in micro and small enterprises (over 80% of the respondents surveyed). Understanding the examined relationships allows micro and small enterprises to consciously shape their development by improving internal management methods and simultaneously building market knowledge, which enable effective business model conversion, adapting to a dynamic environment. Studies suggest that managers of micro and small enterprises ought to treat organizational innovation, not only as internal improvements, but also

as a key tool for acquiring customer and market knowledge. By promoting innovative and more flexible business models among micro and small enterprises, the conducted research, on the one hand, contributes to increasing their resistance to crises and, on the other, improves the competitiveness of local entrepreneurs.

The obtained data provide the basis for concluding that understanding the business model conversion in enterprises cooperating with market partners by examining the relationships between the implementation of innovative organizational solutions and enhancement of customer and market knowledge, in practice may imply the need to invest more in knowledge management tools, digitization of processes and development of employee competence in terms of cooperation with the environment. Moreover, the results of the conducted research can have a positive impact on society, since better understanding of customers leads to the creation of products and services more adapted to real social needs, which may improve the quality of life of consumers and support the development of more inclusive labor markets. Understanding the relationships examined enables managers to consciously shape business model conversion processes and to better adapt the offer to changing customer needs as well as to respond faster to market changes.

It should also be noted that the conducted research provides reliable information, only with certain assumptions and has some limitations that affect the possibility of their empirical application. The limitation of the results obtained is the fact that research does not take into account macroeconomic, legal, demographic and social factors that may affect the business model conversion in enterprises cooperating with market partners. Collaboration with market partners proved to be the foundation of business model conversion in all the firms examined, yet the dominant mechanisms differ in scale. Micro enterprises, which account for more than 97 percent of business entities in the Polish economy, rely on such collaboration mainly to close resource gaps, whereas large enterprises treat it as a lever for expansion and radical innovation. Understanding these differences is essential for selecting suitable management tools, one set for micro enterprises and another for large firms.

The recommendation for the surveyed enterprises is the accurate recognition of the key conditions of the business model conversion, based on innovation and knowledge management. The fact of the occurrence of a significant relationship between the studied relationships determines the business model conversion and an increase in management efficiency and confirms the importance of these relationships. Another significant area of future research, in this respect, should be to examine changes in strategic assumptions of enterprises, enabling long-term development and competing on the market.

References

1. Abolfathi, N., Fosfuri, A., Santamaria, S. (2022). Out of the trap: Conversion funnel business model, customer switching costs, and industry profitability. *Strategic Management Journal*, *43*(9), 1872-1896. https://doi.org/10.1002/smj.3388
2. Amit, R., Zott, C. (2012). Creating value through business model innovation. *MITSloan Management Review*, *53(3),* p. 45.
3. Chan Kim, W., Mauborgne, R. (2005). Value innovation: a leap into the blue ocean. *Journal of Business Strategy*, *26(4),* pp. 22-28. https://doi.org/10.1108/02756660510608521
4. Chesbrough, H. (2010). Business model innovation: opportunities and barriers. *Long range planning*, *43(2-3),* 354-363.
5. Corder, G.W., Foreman, D.I. (2009). *Nonparametric statistics for non‐statisticians*. John Wiley Sons, Inc. https://doi.org/10.1002/9781118165881
6. Davenport, T.H., Eccles, R.G., Prusak, L. (2009). Information politics. In: *The strategic management of intellectual capital* (pp. 101-120). Routledge. https://doi.org/10.4324/9780080517926-11
7. Dubosson-Torbay, M., Osterwalder, A., Pigneur, Y. (2002). E- business model design, classification, and measurements. *Thunderbird International Business Review*, *44*(1), 5-23. https://doi.org/10.1002/tie.1036
8. Fidel, P., Schlesinger, W., Emilo, E. (2018). Effects of customer knowledge management and customer orientation on innovation capacity and marketing results in SMEs: The mediating role of innovation orientation. *International Journal of Innovation Management*, *22(07),* 1850055. https://doi.org/10.1142/S136391961850055X
9. Galvão, G.D.A., Ferrer, P.S.S., Evans, S., Carvalho, M.M.D. (2023). Unpacking the value conversion in a circular business model: exploring the effect of competitive criteria. *Journal of Manufacturing Technology Management*, *34*(2), 265-292. https://doi.org/10.1108/JMTM-05-2022-0198
10. Gebauer, H., Arzt, A., Kohtamäki, M., Lamprecht, C., Parida, V., Witell, L., Wortmann, F. (2020). How to convert digital offerings into revenue enhancement–Conceptualizing business model dynamics through explorative case studies. *Industrial Marketing Management*, *91*, 429-441. https://doi.org/10.1016/j.indmarman.2020.10.006
11. Jung, M.S., Kim, E.H. (2022). A Study of Accelerator Investment Determinants Based on Business Model Innovation Framework. *Asia-Pacific Journal of Business Venturing and Entrepreneurship*, *17*(2), 65-80. https://doi.org/10.16972/apjbve.17.2.202204.65
12. Kovacs, P. (2023). Digital acceleration: How to build a robust enterprise data framework. *Journal of Securities Operations & Custody*, *15*(3), 218-227. https://doi.org/10.69554/HRIL5159

13. Lange, G.S., Johnston, W.J. (2020). The value of business accelerators and incubators–an entrepreneur's perspective. *Journal of Business & Industrial Marketing*, *35*(10), 1563-1572. https://doi.org/10.1108/JBIM-01-2019-0024
14. Łęgowik-Świącik, S. (2023). Creating the Value Network and Converting the Business Model of Technology Companies. *Scientific Papers of Silesian University of Technology. Organization & Management*, *185*. https://doi.org/10.29119/1641-3466.2023.185.16
15. Mohammadi, N., Sakhteh, S. (2023). Start-up accelerator value chain: a systematic literature review. *Management Review Quarterly*, *73*(2), 661-694. https://doi.org/10.1007/s11301-021-00257-2
16. Noviaristanti, S., Acur, N., Mendibil, K., Miranda, E. (2024). The network orchestration role of accelerators for value creation. *IEEE Transactions on Engineering Management*, *71*, 3795-3806. https://doi.org/10.1109/TEM.2024.3356714
17. Prusak, L., Davenport, T.H. (2013). Knowledge after the knowledge creating company: A practitioner perspective. In: *Towards organizational knowledge: The pioneering work of Ikujiro Nonaka* (pp. 255-262). London: Palgrave Macmillan UK. https://doi.org/10.1057/9781137024961_15
18. Saebi, T., Lien, L., Foss, N.J. (2017). What drives business model adaptation? The impact of opportunities, threats and strategic orientation. *Long Range Planning, 50(5),* pp. 567-581.
19. Slywotzky, A.J., Drzik, J. (2005). Countering the biggest risk of all. *Harvard Business Review*, *83*(4), 78-88.
20. Slywotzky, A.J., Morrison, D.J., Andelman, B. (2007). *The profit zone: How strategic business design will lead you to tomorrow's profits*. Crown Currency.
21. Sobko, O.N. (2015). Development of the intelligent agencies network as an enterprise value creation accelerator. *Economic Bulletin of the National Mining University scientific journal*, *52*(52), 129-139.
22. Tong, T., Xu, X., Yan, N., Xu, J. (2022). Impact of different platform promotions on online sales and conversion rate: The role of business model and product line length. *Decision Support Systems*, *156*, 113746.https://doi.org/10.1016/j.dss.2022.113746
23. Vogel, C., Koutsombogera, M., Costello, R. (2020). Analyzing Likert Scale Inter-annotator Disagreement. In: A. Esposito, M. Faundez-Zanuy, F. Morabito, E. Pasero (eds.), *Neural Approaches to Dynamics of Signal Exchanges. Smart Innovation, Systems and Technologies, vol. 151* (pp. 383-393). Singapore: Springer. https://doi.org/10.1007/978-981-13-8950-4_34
24. Willis, G.B. (2016). Questionnaire pretesting. *The SAGE handbook of survey methodology*, *24*, 359-81.

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ARTIFICIAL INTELLIGENCE IN SMALL ENTERPRISE MANAGEMENT – CYBERSECURITY CHALLENGES

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Purpose: Enterprises' use of digital technologies requires cybersecurity measures to protect data, systems, and users from cyber threats. The article aims to present theoretical considerations and empirical research results on cybersecurity management in small enterprises using digital tools in their operations.
Design/methodology/approach: The research was based on two methods. The analysis and literature criticism method allowed for exploring the topic's theoretical basis and developing the methodological assumptions of the empirical study. It was conducted using a diagnostic survey method with a structured interview technique.
Findings: The research analyzed small business cybersecurity challenges. The main problems were found to be limited budgets and the occurrence of complex and dynamic cyberattacks. It is necessary to improve employees' digital competence and cybersecurity awareness.
Research limitations/implications: The survey was a pilot study. It allowed for the verification of the research assumptions and the research tool. The study revealed the relevance of the discussed topic and the need for further in-depth analysis. It is necessary to clarify the survey tool and repeat the survey on a larger sample.
Practical implications: The article examines the aspects of cybersecurity management in small enterprises. It identifies key issues and demonstrates the need to implement practical solutions to prevent cyberattacks.
Originality/value: The value of the article is the development of a research concept enabling a holistic assessment of practices and challenges in the management of cybersecurity of small enterprises in the context of the use of artificial intelligence.
Keywords: cybersecurity, cyberspace, artificial intelligence, small enterprises.
Category of the paper: Research paper.

1. Introduction

With the rapidly changing business environment, small enterprises are confronted with numerous challenges resulting from global social and economic changes and increasing digitization. Turbulent times require not only the ability to adapt flexibly but also the ability to anticipate and respond quickly to changing market conditions. The modern world is described using the BANI (Brittle, Anxious, Non-linear, Incomprehensible) concept, created by J. Cascio (2022). In these circumstances, traditional business models and business methods may prove to be insufficient. Small enterprises, often struggling with limited resources, need to implement modern technologies to increase their resilience to sudden changes and compete effectively in the marketplace. Artificial intelligence (AI) is a supporting tool for these activities. It facilitates rapid processing and analysis of large datasets, automates decision-making processes, and predicts market trends (Mieszajkina, Ostapińska, 2024).

AI is a widely analyzed issue in scientific, journalistic, and political contexts. It involves knowledge modeling, data processing, and algorithm and computational system development, enabling the automatic acquisition, analysis, and use of information. Modern AI systems are characterized by their ability to self-learn, predict patterns based on collected data, and interact with the external environment through sensors and actuators. This process can be conducted autonomously or with human involvement at various stages of the AI life cycle - from design, implementation, and operation, to shutdown and disposal (Portal Sztucznej inteligencji, 2025a).

Understanding AI's capabilities is no longer exclusively the domain of modern technology specialists. Nowadays, it is one of the most important subjects of public debate, as it significantly influences socio-economic transformation processes (Digital Sustainability Forum, 2019). AI has revolutionized the traditional approach to running a business, contributing to the implementation of innovative solutions in various economic sectors. Enables modern business model creation, supports optimization processes, increases operational efficiency, and builds sustainable competitive advantage. It contributes to maximizing profits and dynamic enterprise development.

The first attempt to define the term “artificial intelligence” was made in 1955 by American computer scientist John McCarthy at the Dartmouth Conference, a research workshop dedicated to developing machines capable of intelligent behavior. He described it as „the science and engineering of making intelligent machines” (IAPP, 2023). Currently, the term, despite its widespread usefulness, remains difficult to define clearly because the concept of “intelligence” itself is not precisely defined.

Throughout the years, numerous AI definitions have appeared, reflecting different research approaches. Early approaches focused on the ability of machines to perform functions traditionally reserved for humans (Rich, Knight, 1990). According to R.J. Schalkoff (1990), AI seeks to explain and emulate intelligent behavior through computational methods. Slightly

later, R. Kurzweil (1999) expanded the definition, listing a wide range of systems in the AI area (systems with knowledge base, expert systems, image recognition, machine learning, language recognition, robotics). However, N.J. Nilsson (2014), one of the leading researchers in the field, emphasizes that AI supports the structuring and design of intelligent machines that imitate human intelligence.

In a practical interpretation of the SAS Analytics Platform (2025), AI is considered a technology that allows machines to learn from experience, adapt their actions to new data, and perform tasks typical of humans, such as inference, discovering hidden relationships in data or solving complex problems. Similarly, the PWN Polish Language Dictionary (2025) defines AI as "a branch of computer science that examines the rules governing human mental behavior and creates programs or computer systems that simulate human thinking".

Currently, there is no uniform AI definition in both national legislation and international regulations. A systems approach dominates the literature. This model has been adopted by the OECD, among others, and is reflected in Poland's AI policy. It is interpreted as a system based on the machine concept, which can influence the environment by making recommendations, forecasts, or decisions regarding set goals. It operates on inputs, both machine and human, to: 1) understand real or virtual environments; 2) transform this information into models (manually or automatically); 3) use these models to formulate various outcome options (Portal sztucznej inteligencji, 2025a).

Summarizing these and other AI definitions, it can be concluded that they have evolved from general concepts of automating human activities and functions to more precise approaches involving specific technologies and methods. Despite the differences, the common thread is the perception of AI as systems capable of imitating human cognitive processes to varying degrees of sophistication. As T. Zalewski (2020) indicates, it is more beneficial to emphasize AI's practical applications in various aspects of our lives rather than focusing on precise definitions.

Are small enterprise executives aware of the challenges of operating in an environment of widespread digitization? Do owners and managers see the potential of AI as a tool to increase innovation and growth opportunities for their businesses? Are they aware of the risks involved and are they taking action related to cybersecurity? To answer these questions, a pilot study was conducted to analyze and assess cybersecurity management practices, challenges, and gaps in small enterprises. The originality of the presented considerations lies in the application of a holistic approach to cybersecurity integrating social, organizational and technical-technological dimensions. The need for continuous development of digital competences of employees of small enterprises was also emphasized.

2. Using AI in small business

AI is playing an increasingly important role in enterprises' operations, radically transforming the way they operate, make decisions, and interact with stakeholders. Its impact on business goals is noticeable in large and small economic organizations. Using advanced machine learning algorithms allows products and services to be adjusted to individual consumer expectations. Personalization increases their satisfaction and engagement, which is especially important in a small business (Krystian, Zaskórski, 2023). E. Bielinska-Dusza (2022) indicates such benefits associated with AI use as process automation and advanced data analysis. Routine task automation allows employees to focus on strategic activities. Processing and analysis of large data sets gives the opportunity to better understand market trends, and customer preferences and optimize marketing activities. Forecasting future trends and changes, predicting sales, and supporting business planning processes are also important AI applications. This allows entrepreneurs to manage resources more efficiently, undertake thoughtful marketing and investment activities, and optimize employment. With AI development, enterprises are gaining access to increasingly sophisticated analytical tools to better understand the mechanisms shaping demand and predict consumer response to the products and services on offer. These include, among others (Wodecki, 2018, 2021):

- product recommendation systems used by online platforms,
- automating customer service with chatbots and virtual assistants,
- monitoring social media for feedback on products and services offered,
- personalization of advertising content and conversion prediction, enabling more effective outreach to precisely defined target groups.

In recent years, there has been a rapid increase in AI tools used in Poland. This is confirmed by the data from the global organization PricewaterhouseCoopers' report “Ready for Artificial Intelligence”. Three-quarters of Polish companies have begun implementing AI technologies, mainly to automate processes, detect anomalies and improve prediction quality. However, it should be noted that most of them are only in the early stages of implementation, and only a few are using AI to its full potential. More than half of enterprises (55%) have defined an AI strategy or are working on developing one. This confirms the growing awareness that digital technology use is key to realizing the intended business and financial benefits (PwC, 2024).

The “Power of AI” report published by BUZZcenter (2024) revealed that 77% of surveyed enterprises experience a positive AI impact on their growth. Publicly available AI tools are used by 43% of respondents, solutions adapted to specific enterprise needs are used by 20%, and 14% have implemented dedicated AI tools. Only 15% of respondents declare not using AI currently, but plan to implement its tools in the short term, while 8% of respondents are not using this type of technology and do not intend to implement it. The report's authors emphasize that companies recognize AI's potential, indicating its benefits such as time savings, process

automation, reduced operating costs, predictive capabilities, innovation, better risk management, and improved product and service quality.

The 2024 "Business Digital Transformation Monitor" research was conducted by a global organization of independent enterprises KPMG in partnership with Microsoft. They were attended by 180 managers who are responsible for digitization issues in their organizations. Large enterprises were represented by 31% of people, medium enterprises by 39%, and small enterprises by 30%. Nearly a third of respondents declared they would use AI tools, while another 30% plan to implement them in the current year. Smaller enterprises tend to implement these technologies at a lower level, not because they are unaware of their importance, but due to limited resources and insufficient experience in digitally transforming their organizational processes. Certainly small business needs more support in achieving digital maturity (KPMG, Microsoft, 2024).

According to a survey conducted by AI Chamber (2024) among 350 decision-making employees of small and medium-sized enterprises (SMEs) from Poland, the Czech Republic, Estonia, and Romania, 9 out of 10 surveyed entities are using AI and machine learning (ML), with one in four using it to a significant degree. This has a positive impact on the following areas of their business: IT, marketing, customer service, administration, sales, logistics, production, quality control. Two-thirds of survey participants are convinced that AI and ML positively impact their businesses. Half of the respondents see the potential of these technologies to build competitive advantage, and more than 40% predict positive financial effects from their implementation. Only 4% of respondents have a negative perception of AI and ML. However, implementing AI tools in SMEs is associated with certain difficulties. These include, for example, lack of confidence in digital technologies, high implementation costs, lack of adequate infrastructure, inadequate staff competence, and difficulty in recruiting qualified professionals.

E. Bielinska-Dusza (2022) also emphasizes that despite the growing use of AI technologies in both large and small enterprises, the process still encounters numerous barriers. She divides them into four types:

1. barriers resulting from the AI technology's limitations (related to the state of the existing knowledge and scientific and technological base),
2. intra-organizational barriers (strategic, resource, and time pressure related to the development and implementation of digital tools),
3. external barriers (from the environment),
4. hybrid barriers, resulting from the interaction of the first three.

L.S. Dalenogare et al. (2018) emphasize that overcoming barriers requires not only identifying them, but first and foremost understanding their causes, effects, and multidirectional interrelationships that hinder AI technology implementation.

The Ministry of Development and Technology, with support from the European Commission under the Technical Support Instrument, has implemented the project "Advancing The Digital Transformation of Polish Enterprises" (2024). The research results confirm that the digitization advancement level of SMEs in Poland is low, with its pace limited by financial, resource, technological, organizational, competence, and psychological factors.

Many digitization barriers result from the specific SME characteristics (Mieszajkina, 2020). Entities in this sector most often finance their operations from their resources and have little access to the capital market, which limits their ability to invest in digitization. Many entities lack sufficient knowledge of available EU funding sources. The decisive owner's role and lack of ability and willingness to delegate authority result in one-man decision-making, with a focus on day-to-day operations instead of strategic development. Lack of process formalization and action planning means that digitization is not a priority, and actions are ad hoc and unsystematic. Several technological barriers are related to inadequate and mismatched infrastructure to the business nature, as well as the lack of professionals with the appropriate digital skills. SMEs typically do not employ staff with specialized IT training, and owners' knowledge of new technologies is often limited. Digital competence development is based on short-term market needs and on taking advantage of emerging training opportunities. This is not conducive to gaining strategic knowledge and skills in AI and cybersecurity. Consequently, many decisions regarding the digitization of operations rely on intuition rather than analysis and strategic planning. Moreover, the small scale of operations and labor-intensive nature of production lead to technologies being treated as an unnecessary cost rather than an investment in development (Mieszajknia, Bochen, 2022; Scoutto et al., 2021). All this makes digital transformation chaotic, without clearly defined goals and plans.

Despite the clear barriers, SMEs have the potential to reap significant benefits from the implementation of digital and AI tools, such as increased productivity, reduced costs, increased customer satisfaction, and enhanced competitiveness. By doing so, they can greatly enhance their chances of achieving success and strategic growth.

3. Artificial intelligence challenges - cybersecurity

Advances in AI bring new opportunities, challenges, and threats to its users. A significant problem is the increasing risk of committing crimes related to security breaches of processed information and the misuse of mass media to disseminate prohibited content. Crimes involving the instrumental use of networks and information systems to violate legally protected interests under criminal law are also a significant threat (Siwicki, 2012). Therefore, it is important to take action to secure the cyberspace in which enterprises operate.

Over the years, numerous theoretical concepts and analytical approaches to cyberspace have developed. M. Jurek (2023) considers it from two perspectives. In a broad (abstract) sense, he defines it as a global information infrastructure that enables people to connect through computers and telecommunications. In a narrower sense - as a communication space created by a system of Internet links, facilitating users to interact in the real world. Similarly, P. Sienkiewicz (2009) considers cyberspace as a kind of communication space created by a system of Internet connections. He indicates two aspects:

1. positive, in which it is an area for cooperation on many levels (including social, economic or security),
2. negative, taking various forms (including cybersurveillance, cybercrime, cyberterrorism or cyberwarfare).

According to the U.S. Department of Defense, cyberspace is a global domain in the information environment, consisting of an interdependent network of information technology infrastructures, including the Internet, telecommunications networks, computer systems, and embedded processes and controllers (Ottis, Lorents, 2010).

C. Banasiński (2018, p. 31) understands the term cybersecurity as "the process of ensuring the safe functioning in cyberspace of the state as a whole, its structures, individuals, legal and other entities, and information resources in global cyberspace". R.A. Kemmerer (2003, p. 3) believes that „cybersecurity consists largely of defensive methods used to detect and thwart would-be intruders". J.A. Lewis (2006, p. 1) defines it as „cybersecurity entails the safeguarding of computer networks and the information they contain from penetration and malicious damage or disruption". E. Amoroso (2006) emphasizes that for ensuring cybersecurity, activities, technologies, and practices are necessary to minimize the risk of malicious attacks on information systems. This includes a variety of protection mechanisms such as intrusion detection and prevention systems, anti-virus software, solutions to block unauthorized access, multi-component authentication mechanisms, and technologies to ensure secure and encrypted communications. According to D. Craigen and N. Diakun-Thibault (2014), understanding the nature of cybersecurity requires a multidisciplinary approach. The phenomenon is adversarial, where some users aim to protect computer systems, while others utilize information technology to breach their security features. Effective protection cannot be limited to traditional disciplines such as mathematics, computer science, or electrical engineering, but requires interdisciplinary analysis.

C. Banasinski and M. Rojszczak (2023) define cybersecurity as a multidimensional process involving integrated measures to protect against threats from cyberspace. The authors emphasize that effective digital security requires technical, legal, and organizational measures to respond to dynamically evolving challenges and threats effectively. Their analysis highlights the complexity of protecting both data and infrastructure and information, indicating the need to improve strategies and tools to effectively counter cyberattacks continuously.

The threat of cyber attacks, data breaches, and digital content theft is a concern for all organizations. In the US, 43% of all cybercrime incidents target SMEs. A major factor undermining security systems is the human element—often it is not the IT systems, but users who represent the weakest link in the cybersecurity framework (PBSG, 2021).

According to the taxonomy proposed by W. Nowak (2020), cybersecurity incidents can be divided into three groups: 1) malware attacks; 2) identity theft; and 3) attacks that block access to services. Their main goals are to steal data, disrupt operations, cause financial damage, and permanently or temporarily disable systems.

Organizations belonging to different sectors and operating in different industries process increasingly large sets of data in the course of their business activities. This trend intensified during the pandemic, when most operations were moved to computer networks and virtual spaces. Technological changes have increased enterprises' development potential, but also raised the number and degree of risks. The already known threats (phishing, pharming, DDoS attacks, brute force attacks, bots and Trojans, ransomware) have been joined by new ones with AI development, often being modifications or enhancements to existing ones. These include, among others: telephone bots, deepfakes, GPT chat, fake news, data theft and system hacking. To ensure the safety and effective use of AI, these risks must be considered when developing a cybersecurity strategy.

Awareness among organizational executives about both the benefits and risks of using digital tools is growing every year. This is confirmed by data from KPMG reports in recent years. Indeed, in 2023, 15% of companies in Poland were using AI technology, and 13% planned to implement it by the end of the year (KPMG, Microsoft, 2023). By 2024, one-third of companies stated they would implement digital tools, and an additional 30% indicated they would do so soon (KPMG, Microsoft, 2024). As more organizations invest in digital technologies, concerns about their potential misuse also increase. The “Power of AI” report shows that 42% of respondents are concerned about the lack of adequate protection against cyber attacks that could disrupt AI or allow unauthorized access to sensitive data. Simultaneously, up to 30% of enterprises are not taking any special measures to prepare them for possible AI system failures (BUZZcenter, 2024).

In SMEs, implementing AI-based solutions and protecting against cyber threats is more challenging than in large organizations. Effective cybersecurity management is crucial in a rapidly changing environment where digital technologies play a significant role, regardless of the size of operations. It is essential for maintaining the integrity, confidentiality, and availability of data, which is vital for the organization's stability and security. Cybercriminals are developing increasingly sophisticated attack methods, and their activities are increasingly targeting the small business sector. Smaller business units typically have limited resources to provide effective cyber protection. Therefore, the implementation of technological security measures alone proves to be insufficient. It is necessary to adopt

a comprehensive approach to cybersecurity that considers not only technological aspects but also the organizational and human factors that are crucial to effectively countering threats.

As part of European Cyber Security Month 2024, recommendations have been made for representatives of the SME sector on what measures to take to protect the company from cyber attacks. These include (European Commission, 2024):

- increase education and deepen employee awareness,
- software update,
- setting strong passwords and two-factor authentication,
- regular backups and safe storage,
- implementing a security policy that regulates technology use, and data access, outlines procedures for security breaches,
- cooperation with experts specializing in cybersecurity.

Despite concerns, using AI by SMEs does not have to involve large expenditures, due to:

1. availability of ready-made solutions - today's market offers many ready-made AI-based tools and platforms that are available in subscription or "as-a-service" models (Creativa, 2024; Symfonia, 2024),
2. AI cloud services - enterprises pay only for the resources consumed, allowing them to scale services according to their needs and budget capabilities (Biznes.gov.pl, 2024; Vestigio, 2024),
3. process automation (Let's automate, 2025; Symfonia, 2024),
4. open-source solutions - there are many free and open-source AI tools and libraries (DigitalOcean, 2025),
5. implementation simplicity (Antczak, 2024),
6. training and educational resources availability (Portal Sztucznej Inteligencji, 2025b; Microsoft, 2024).

With these capabilities, SMEs can deploy AI solutions more cost-effectively (less costly) and more easily, making the technology more accessible to businesses with limited resources, while also enabling protection against cybercrime.

4. Research methodology

The survey was conducted based on a procedure consisting of several stages. Firstly, a comprehensive review of the literature regarding the use of artificial intelligence in business management, with an emphasis on cybersecurity aspects, was conducted. The following steps identified the research problem, posed research questions, and formulated hypotheses.

The research problem is the following: What are the existing practices, challenges and gaps in small enterprise cybersecurity management efforts? Three research questions were formulated:

1. What steps small enterprises are taking to protect themselves from cybersecurity incidents?
2. What are the barriers to managing cybersecurity in small enterprises?
3. What are the most relevant activities in the context of improving cybersecurity management in small enterprises?

The research's main objective was to analyze and assess the practices, challenges and gaps in the area of cybersecurity management in small enterprises. The following hypotheses were formulated:

- Hypothesis 1: In small enterprises, cybersecurity management activities are based on widely available solutions that do not require specialized knowledge and skills.
- Hypothesis 2: Cybersecurity management in small enterprises is most hindered by a limited investment budget and insufficient employee knowledge in the cybersecurity area.
- Hypothesis 3: Improving cybersecurity management requires implementing activities aimed at developing employees' competencies and increasing their awareness of information and communication technology's safe use.

Hypothesis testing was conducted based on a pilot study. The authors intended to verify their knowledge of the phenomenon under study and to test the research tool. The hypotheses were verified using the diagnostic survey method, a structured interview technique. The interview questionnaire contained 6 substantive questions and 3 metric questions. Respondents answered substantive questions on a five-point Likert scale. Due to the pilot nature of the study, it was conducted on a relatively small sample, 15 small enterprise owners participated in 2024. The entities represented by the respondents during the research met the criteria defined in the Act of 6 March 2018 – Entrepreneurs' Law (Dz.U. z 2024, poz. 236).

Research sample structure:

- age of the enterprise: from 1 to 5 years - 5 enterprises, from 5 to 10 years - 4, over 10 years - 5, less than one year - 1,
- place of business: city of more than 150 thousand inhabitants - 3 enterprises, city of 50 to 150 thousand - 4, city of 20 to 50 thousand - 4, city of up to 20 thousand inhabitants - 3, village - 1,
- industry: wholesale and retail trade - 3 enterprises, IT - 2, financial activities and insurance - 2, industry - 2, service activities - 6.

5. Cybersecurity in small enterprises – research results

As digital technologies rapidly evolve, cybersecurity becomes a crucial element of any organization's strategy, including those of small businesses. Growing cybercrime threats are forcing executives to take action to protect data and information systems. Investing in the employment of highly qualified professionals with the appropriate skills in this sphere is now becoming strategic for risk management in the organization. As part of the survey, respondents were asked to whom in their enterprises were entrusted with cyber security tasks. The responses obtained are as follows:

- enterprise has a dedicated cybersecurity position: 5 enterprises (33.3%),
- cybersecurity tasks are outsourced (rather sporadically): 6 enterprises (40%),
- planned to create cybersecurity specialist positions in the future: 3 enterprises (20%),
- employing such a specialist is not necessary: 1 enterprise (6.7%).

To verify hypothesis 1, respondents were asked to answer two questions. The first concerned the frequency of cybersecurity incidents. Responses were given on a scale from 1 - never to 5 - very often. The answers are presented in Table 1.

Table 1.
Frequency of appearing cyber security incidents

Rating	**1**	**2**	**3**	**4**	**5**
Number of respondents	3	4	5	2	1

Source: own elaboration.

For three enterprises (20%), cyber incidents were not reported. In nine units (60%) these events occurred infrequently (answers 2 and 3). This may indicate the presence of quite good security features. Three people (20%) gave answers 4 and 5, meaning that they often experience problems in the cybersecurity area. The vast majority of enterprises surveyed are experiencing problems related to operating in cyberspace, indicating significant challenges in protecting data and information systems.

In the second question, respondents indicated the actions they are taking to secure the company against cyber threats. The responses are presented in Table 2, where 1 means - we do not take action, and 5 - we take action constantly.

Table 2.
Actions to secure the company from cyber threats (number of respondents)

Actions	**Ratings**					**Weighted sum of ratings**
	1	**2**	**3**	**4**	**5**	
Regular updates of software and operating systems	0	1	1	7	6	63
Installation of antivirus and antimalware software	0	1	2	6	6	62
Monitoring network traffic and security events	0	1	4	5	5	59
Collaborating with cybersecurity experts	0	2	3	6	4	57
Implementation of information security policies	0	2	4	5	4	56

Cont. table 2.

Training employees on cyber security	1	2	4	5	3	52
Regular assessment of cyber security risks	1	3	5	4	2	48
Adjusting the crisis management plan for cyber security incidents	2	4	3	4	2	45
Regular use of external cyber security specialists	4	3	4	3	1	39

Source: own elaboration.

The vast majority of surveyed enterprises regularly update software and operating systems (weighted sum of ratings 63). Another activity with a similar score is the installation of antivirus and antimalware software (weighted sum of ratings 62). Quite often surveyed units monitor network traffic and security events (weighted sum of ratings 59). Enterprises are less likely to use external cybersecurity specialists (weighted sum of ratings 39). Also infrequent are activities related to correcting the crisis management plan in case of cyber incidents (weighted sum of ratings 45) and assessing cybersecurity risks (weighted sum of ratings 48). The answers obtained allow the conclusion that actions based on generally available solutions, which do not require specialized knowledge and skills, are more often taken. It is disturbing that half of the surveyed enterprises do not pay much attention to employee training in cybersecurity (7 respondents answered 1, 2, 3). This is due to both the limited ability to implement internal and external training and the owners' lack of belief in the necessity of these activities. Considering that the vast majority of those surveyed are dealing with cyberattack incidents, basing cybersecurity management strategies on publicly available solutions is insufficient. The analysis of the responses does not provide a reason to reject Hypothesis 1.

The verification of hypothesis 2 was conducted through a question regarding the degree of influence that specific barriers have on the cybersecurity management process. Respondents provided answers on a scale from 1 - no influence to 5 - significant influence (Table 3).

Table 3.
Barriers to managing cyber security in the enterprise (number of respondents)

Barriers	**Ratings**					**Weighted sum of ratings**
	1	**2**	**3**	**4**	**5**	
Limited budget for investments in cyber security solutions and tools	0	1	3	5	6	61
Threats from phishing attacks, ransomware and other malware forms	0	1	4	6	4	58
The complexity and dynamic nature of cyber threats, which are constantly evolving	0	1	6	4	4	56
The need to ensure security for remote and mobile working	0	2	5	5	3	54
Lack of resources for ongoing employee cyber security training	1	1	4	6	3	54
The need to comply with data security regulations and legal requirements (e.g., RODO, GDPR)	0	2	5	6	2	53
Lack of employee awareness of cyber threats and proper security practices	1	2	5	4	3	51
Lack of adequately trained information security specialists	0	3	6	3	3	51
Difficulty in monitoring and detecting cybersecurity incidents	0	2	7	4	2	51
Limited access to qualified cybersecurity professionals	1	2	5	4	3	51
Limited employee knowledge of new technologies and cybersecurity trends	0	3	7	3	2	49

Cont. table 3.

Lack of clearly defined policies and procedures for enterprise cyber security management	1	2	6	4	2	49
Lack of management understanding of the importance of cyber threats	3	4	3	3	2	42

Source: own elaboration.

For most enterprises, the biggest barrier is a limited budget to invest in solutions and tools to ensure effective cybersecurity management (weighted sum of ratings 61). Threats from cyber-attacks involving various forms of malware are also a significant challenge (weighted sum of ratings 58). The complexity and dynamic nature of cyber threats (weighted sum of ratings 56) make cybersecurity management quite difficult. The barriers that an overwhelming number of respondents felt were less challenging in terms of cybersecurity management were management's lack of understanding of the importance of cyber threats (weighted sum of ratings 42), lack of clearly defined related policies and procedures (weighted sum of ratings 49), and limited employee knowledge of new technologies and trends in cybersecurity (weighted sum of ratings 42). Responses analysis reveals that hypothesis 2 has been positively verified in the first part - the biggest barrier to cybersecurity management are problems related to funding cybersecurity activities. However, there are reasons to reject hypothesis 2 in its second part - limited knowledge of employees related to cybersecurity in the opinion of respondents is not a significant barrier. Representatives from 10 of the 15 enterprises indicated ratings of 2 and 3, meaning low and medium impact.

Three questions were used to verify hypothesis 3. Initially, interview participants were asked to evaluate the effectiveness of the measures the company is taking in the cybersecurity management area. The responses are presented in Table 4, where 1 means no effectiveness and 5 means very high effectiveness.

Table 4.
Effectiveness of the enterprise's cyber security management efforts

Rating	**1**	**2**	**3**	**4**	**5**
Number of respondents	1	2	7	4	1

Source: own elaboration.

Five respondents (33.3%) believe that the cybersecurity management activities undertaken at their company are highly effective (ratings 4 and 5). Seven respondents (46.6%) assessed their effectiveness at an average level (rating 3), and three respondents (20%) responded that the measures were not effective (ratings 1 and 2). The results indicate that the majority of respondents (80%) perceive cybersecurity management activities as at least moderately effective. This means there is space for improvement in enterprises to implement more effective cybersecurity strategies and tools.

Therefore, respondents were asked whether there was a need to improve cybersecurity management at their enterprises (Table 5). They gave their answers on a scale of 1 - does not need improvement, and 5 - improvement is absolutely necessary.

Table 5.
The need to improve cyber security management in the enterprise

Rating	**1**	**2**	**3**	**4**	**5**
Number of respondents	0	1	1	5	8

Source: own elaboration.

The vast majority of respondents (86.6%) recognize the need to improve cybersecurity management (ratings 4 and 5). This indicates a high risk awareness and the need for further action in this area. A small percentage of respondents (13.4%) view this need as less important, possibly due to various factors, such as the effectiveness of existing safeguards or their assessment of risk.

What actions can be most useful in improving cybersecurity management? Respondents answered this question on a scale from 1 - not very helpful to 5 - very helpful. Their opinions are presented in Table 6.

Table 6.
Assessment of actions needed to improve cyber security management at the enterprise (number of respondents)

Actions	**Ratings**					**Weighted sum of ratings**
	1	**2**	**3**	**4**	**5**	
Raising employees' awareness of safe use of information and communication technologies	0	1	3	5	6	61
Implementation of a regular cyber security training program for all employees	0	1	3	6	5	60
Implementation of technologies to protect against phishing attacks, ransomware and other threats	0	1	3	6	5	60
Creating a system of regular updates and contingency testing (e.g., backups, system recovery plans)	0	1	3	6	5	60
Implementation of tools for sensitive data encryption and communications	0	1	4	5	5	59
Regular cybersecurity reviews and audits	0	1	3	7	4	59
Updating and strengthening information security policies and internal procedures	0	1	4	6	4	58
Implementation of cyber security incident monitoring and detection systems	0	1	4	6	4	58
Establishing cyber risk management procedures and developing an incident response plan	0	1	4	6	4	58
Development and implementation of strategies to ensure security in remote and mobile work	0	1	5	5	4	57
Introducing systems to control access to data and monitor user activity	0	2	6	4	3	53
Collaboration with external information security specialists	1	2	5	5	2	50

Source: own elaboration.

Among the representatives of the surveyed enterprises (11 individuals, accounting for 73.3% of the total) believe that increasing employee awareness regarding the safe use of digital technologies is the most crucial factor (weighted sum of ratings 61). Respondents expressed a similar opinion on actions such as implementing a regular cybersecurity training program, introducing technologies to protect against cyberattacks, and creating a system of regular updates and contingency testing (in each case, the weighted sum of the ratings is 60). Slightly

surprisingly, the importance of introducing systems to control access to data and monitor user activity (weighted sum of ratings 53) and working with external information security specialists (weighted sum of ratings 50) was underestimated. Based on the feedback from respondents, activities aimed at enhancing employees' skills and awareness regarding the safe use of digital technologies are deemed necessary. Since these initiatives received the highest weighted ratings, there is no reason to reject Hypothesis 3.

6. Discussion and conclusions

The survey provided important insights into the challenges of managing cybersecurity in small enterprises. Respondents indicated several barriers, including a lack of specialized knowledge, limited financial resources, and insufficient awareness of cyber threats among employees. They evaluated the effectiveness of their enterprises' cybersecurity management at an average level. Meaning that they are aware of the need to improve activities aimed at strengthening the cyberspace operations security. The willingness to develop employees' digital competence and cybersecurity awareness can be assessed positively. The inevitable digitization of business processes and the growing complexity of cyber threats mean that enterprise digital security is no longer solely an IT specialist's domain. Increasingly, employees' decisions, habits, and levels of awareness are the organization's first and most important defense line. A significant part of security breaches are due not to advanced technical attacks, but to mistakes or employee ignorance. This indicates the importance of building cybersecurity awareness throughout the organization.

The problem for many small enterprises is IT infrastructure – from firewalls to servers and software, which has not been updated for years. Outdated solutions usually have weaker encryption mechanisms, gaps in authentication protocols and lack of manufacturer support, which significantly increases the risk of hacking and data leaks. The lack of modernization of the technical and technological environment increases the cybersecurity gap and limits the practical benefits of AI tools. Investments in hardware updates, patch management and security-by-design policies are crucial for small enterprises to be able to safely and effectively use artificial intelligence. As studies have shown, limited financial resources are a significant barrier to such modernization.

The conducted survey was a pilot and included a small respondent group, implying some limitations on the ability to generalize the results. However, the data obtained provide an important beginning point for further, more extensive analysis. During the interviews, it was noted that some questions were difficult for respondents due to the use of specialized terminology, so the survey tool should be clarified. The authors intend to conduct a broader study to identify differences in cybersecurity management depending on the enterprise's time

in the market, location, and industry. Future research will also include the possibility of evaluating the effectiveness of specific AI tools in minimizing cyber threats.

The study literature and empirical research presented showed that effective cybersecurity management in small enterprises requires a holistic approach, combining the development of digital competencies, the implementation of modern protective technologies, and the formation of a digital security culture. Small enterprise owners have a crucial role in this. They are the ones who, through their decisions and behavior, set the standards for employees. It is important to treat security as an integral part of their business processes, not as an obstacle or additional burden.

The innovative element of the presented research was the combination of two perspectives: 1) the use of AI in small enterprises and 2) cybersecurity management in this context. This allowed for a comprehensive approach to the level of awareness, practices and barriers occurring in these processes. The results of the empirical research are consistent with the conclusions drawn from the literature review. They confirm the low digital maturity of SMEs and the lack of specialist competences enabling the effective and safe use of AI tools. The information obtained is of practical and cognitive importance, as it shows real competence and organizational gaps in the small enterprise sector and indicates the need for broader support for this sector in the context of the development of digital competences and AI implementation.

References

1. AI Chamber (2024). *Rola AI w MŚP.* Retrieved from: https://aichamber.eu/report/raport-ai-chamber-2024-rola-ai-w-msp/, 28.02.2025.
2. Amoroso, E. (2006). *Cyber Security.* Summit, New Jersey, NJ: Silicon Press.
3. Antczak, J. (2024). *Wykorzystanie sztucznej inteligencji (AI) w małych i średnich firmach.* Retrieved from: https://jacekantczak.pl/wykorzystanie-sztucznej-inteligencji-%28ai%29-w-malych-i-srednich-firmach, 13.03.2025.
4. Banasiński, C., Rojszczak, M. (2023). *Cyberbezpieczeństwo. Zarys wykładu.* Warszawa: Wolters Kluwer.
5. Bielińska-Dusza, E. (2022). Transformacja technologiczna przedsiębiorstw jako skutek zastosowania sztucznej inteligencji. *Organizacja i Kierowanie, No. 1(190),* pp. 159-176.
6. Biznes.gov.pl (2024). *AI, Big Data i chmura obliczeniowa – jak nowe technologie mogą zrewolucjonizować małe i średnie przedsiębiorstwa.* Retrieved from: https://www.biznes.gov.pl/pl/portal/004811?utm_source=chatgpt.com, 14.03.2025.
7. BUZZcenter (2024). *Power of AI. Nowe możliwości rozwoju i skalowania biznesu w polskich realiach.* Retrieved from: http://buzzcenter.pl/wp-content/uploads/2024/09/RAPORT_Power-of-AI_BUZZcenter-2024.pdf, 28.02.2025.

8. Cascio, J. (2022). *Human responses to a BANI World.* Retrieved from: https://medium.com/@cascio/human-responses-to-a-bani-world-fb3a296e9cac, 13.03.2025
9. Craigen, D., Diakun-Thibault, N., Purse, R. (2014). Defining Cybersecurity. *Technology Innovation Management Review, Vol. 4, No. 10,* pp. 13-21.
10. Creativa. (2024). *AIaaS – czym jest sztuczna inteligencja (AI) jako usługa? AI Act i inne prawne aspekty.* Retrieved from: https://creativa.legal/aiaas-czym-jest-sztuczna-inteligencja-ai-jako-usluga/, 14.03.2025.
11. Dalenogare, L.S., Benitez, G.B., Ayala, N.F., Frank, A.G. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal of Production Economics*, *Vol. 204*, pp. 383-394.
12. Digital Sustainability Forum. (2019). *Sztuczna inteligencja jako element zrównoważonego rozwoju gospodarczo-społecznego*. Warszawa: Digital Sustainability Forum.
13. DigitalOcean. (2025). *10 open source AI platforms for innovation.* Retrieved from: https://www.digitalocean.com/resources/articles/open-source-ai-platforms, 13.03.2025.
14. IAPP Research and Insights (2023). *International Definitions of Artificial Intelligence.* Retrieved from: http://hai.stanford.edu/sites/default/files/2020-09/AI-Definitions-HAI.pdf, 21.02.2025.
15. Jurek, M. (2023). Cyberprzestępczość w dobie transformacji cyfrowej państwa. Analiza wybranych problemów. *Transformacje*, *Vol. 1, No. 116*, pp. 45-60.
16. Kemmerer, R.A. (2003). Cybersecurity. In: *25th International Conference on Software Engineering. Proceedings* (pp. 705-715). Portland, OR: IEEE.
17. Komisja Europejska (2024). *Europejski Miesiąc Cyberbezpieczeństwa 2024: #ThinkB4UClick.* Retrieved from: https://commission.europa.eu/news/european-cybersecurity-month-2024-thinkb4uclick-2024-10-01_pl, 22.02.2025.
18. KPMG, Microsoft (2023). *Sztuczna inteligencja w firmach w Polsce: potencjał do wykorzystania.* Retrieved from: https://kpmg.com/pl/pl/home/media/press-releases/2023/07/media-press-sztuczna-inteligencja-w-firmach-w-polsce-potencjal-do-wykorzystania.html, 21.02.2025.
19. KPMG, Microsoft (2024). *Monitor Transformacji Cyfrowej Biznesu. Odkrywanie nieznanych ścieżek w cyfrowym świecie. Edycja 2024.* Retrieved from: https://kpmg.com/pl/pl/home/insights/2024/04/monitor-transformacji-cyfrowej-biznesu-edycja-2024.html, 28.02.2025.
20. Krystian, M., Zaskórski, P. (2023). Sztuczna inteligencja w usprawnianiu procesów biznesowych. *Nowoczesne Systemy Zarządzania, Vol. 18, No. 4*, pp. 15-22.
21. Kurzweil, R. (1999). *The Age of Spiritual Machines*. New York, NY: Penguin Books.
22. Let's automate (2025). *Automatyzacja i sztuczna inteligencja, czyli efektywność do kwadratu.* Retrieved from: https://www.letsautomate.pl/post/automatyzacja-i-sztuczna-inteligencja-czyli-efektywnosc-do-kwadratu, 13.03.2025.

23. Lewis, J.A. (2006). *Cybersecurity and Critical Infrastructure Protection*. Washington, DC: Center for Strategic and International Studies.
24. Microsoft. (2024). *Microsoft ogłasza inwestycję w szkolenia AI w Polsce – milion osób zdobędzie nowe kompetencje.* Retrieved from: https://news.microsoft.com/pl-pl/2024/11/28/microsoft-oglasza-inwestycje-w-szkolenia-ai-w-polsce-milion-osob-zdobedzie-nowe-kompetencje/, 13.03.2025.
25. Mieszajkina, E. (2020). *Współczesne trendy w zarządzaniu małymi przedsiębiorstwami.* Lublin: Politechnika Lubelska.
26. Mieszajkina, E., Bochen, P. (2022). Assessment of Digital Competences of Lublin Province Residents in Relational Terms. *Scientific Papers of Silesian University of Technology. Organization and Management Series, No. 166*, pp. 545-563.
27. Mieszajkina, E., Ostapińska, K. (2024). Evaluation of the Impact of the BANI World on Small Business Innovation Activities. *European Research Studies Journal, Vol. 27, No. 3*, pp. 272-288.
28. Ministerstwo Rozwoju i Technologii (2024). *Advancing the digital transformation of polish enterprises - Current State Report.*
29. Nilsson, N.J. (2014). *Principles of Artificial Intelligence*. Palo Alto, CA: Morgan Kaufmann.
30. Nowak, W. (2020). Specyfika zagrożeń w cyberprzestrzeni. In: C. Banasiński, M. Rojszczak (Ed.), *Cyberbezpieczeństwo* (pp. 145-168). Warszawa: Wolters Kluwer.
31. Ottis, R., Lorents, P. (2011). Cyberspace: Definition and implications. *5th European Conference on Information Management and Evaluation, ECIME*, pp. 267-270.
32. PBSG. (2021). *Typy cyberataków, które zagrażają bezpieczeństwu w firmach.* Retrieved from: https://www.pbsg.pl/typy-cyberatakow/, 28.02.2025.
33. Portal sztucznej inteligencji (2025a). *Czym jest sztuczna inteligencja.* Retrieved from: https://www.gov.pl/web/ai/czym-jest-sztuczna-inteligencja2, 02.03.2025.
34. Portal sztucznej inteligencji (2025b). *Programy wdrożeniowe.* Retrieved from: https://www.gov.pl/web/ai/programy-wdrozeniowe, 13.03.2025.
35. Prawo przedsiębiorców (2018). *Dziennik Ustaw Rzeczpospolitej Polskiej.*
36. PwC (2024). *Gotowi na sztuczną inteligencję*. Warszawa: PwC Polska.
37. Rich, E., Knight, K. (1990). *Artificial Intelligence*. New York, NY: McGraw Hill Science.
38. SAS (2024). *What is artificial intelligence?* Retrieved from: https://www.sas.com/pl_pl/insights/analytics/what-is-artificial-intelligence.html, 11.03.2025.
39. Schalkoff, R.J. (1990). *Artificial Intelligence: An Engineering Approach*. New York, NY: McGraw Hill College.
40. Scoutto, A.S., Miotti, M.A., Ministrero, S.G. (2021). Digital capabilities and their influence on business strategies and performance within SMEs. *Technology Analysis & Strategic Management, Vol. 33, No. 12,* pp. 1445-1459.

41. Sienkiewicz, P. (2009). Terroryzm w cybernetycznej przestrzeni. In: T. Jemioło, J. Kisielnicki, K. Rajchel (Ed.), *Cyberterroryzm – nowe wyzwania XXI wieku* (pp. 89-105). Warszawa: Akademia Obrony Narodowej.
42. Siwicki, M. (2012). Podział i definicje cyberprzestępstw. *Prokuratura i Prawo*, *No. 7-8*, pp. 45-58.
43. *Słownik języka polskiego PWN* (2025) Retrieved from: https://sjp.pwn.pl/sjp/sztuczna-inteligencja;2466532.html, 21.02.2025.
44. Symfonia (2024). *Sztuczna Inteligencja w MŚP: zastosowania, korzyści i wyzwania* Retrieved from: https://symfonia.pl/blog/finanse-i-ksiegowosc/poradnik-ksiegowej/sztuczna-inteligencja-w-msp-zastosowania-korzysci-i-wyzwania/, 14.03.2025.
45. Vestigio (2024). *Przetwarzanie w chmurze a AI – Jak sztuczna inteligencja działa?* Retrieved from: https://vestigio.agency/pl/artificial-intelligence/przetwarzanie-w-chmurze-a-ai-jak-sztuczna-inteligencja-dziala-w-srodowiskach-cloud/, 13.03.2025.
46. Wodecki, A. (2018). *Sztuczna inteligencja w kreowaniu wartości organizacji*. Kraków: Wydawnictwo Uniwersytetu Ekonomicznego w Krakowie.
47. Wodecki, A. (2021). *Sztuczna inteligencja we współczesnych organizacjach. Jak automatyczne systemy mogą wpływać na firmy, modele biznesowe, rynki?* Warszawa: PWN.
48. Zalewski, T. (2020). *Prawo sztucznej inteligencji.* Warszawa: C.H. Beck.

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COMPARATIVE EFFECTIVENESS OF VIRTUAL REALITY VS. AUGMENTED REALITY IN WELDING OPERATOR TRAINING

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Purpose: This study investigates the comparative effectiveness of Virtual Reality (VR) and Augmented Reality (AR) technologies in welding operator training, with a focus on perceived realism and potential for skill transfer. Given the high-risk nature of welding, the research explores safer and more efficient alternatives to traditional hands-on instruction.
Design/methodology/approach: A total of 40 certified welders with at least five years of experience participated in a controlled comparison of VR and AR training systems at a laboratory in the Walbrzych Special Economic Zone in Poland. Both systems were enhanced with standardized instructions based on the Training Within Industry (TWI) Job Instruction method. After practicing the same welding task in both environments, participants rated the realism of each experience using a 5-point Likert scale. A paired sample t-test was used to assess statistical significance.
Findings: The results show that AR training was perceived as significantly more realistic than VR, with average ratings of 4.13 and 2.55 respectively. Participants highlighted the physical interaction with real tools and objects in AR as a major factor contributing to this realism. VR, while immersive and safe, lacked haptic feedback and physical context, which reduced its perceived authenticity. The findings support the use of AR for enhancing skill transfer and suggest a blended training model using both technologies.
Research limitations/implications: This study focuses on subjective assessments of realism without measuring actual skill improvement post-training. Future research should incorporate objective performance evaluations and explore long-term learning outcomes.
Practical implications: The study provides evidence for training designers and manufacturers on how to integrate AR and VR in welding instruction. AR shows promise for improving trainee readiness and reducing material costs, while VR remains valuable for safe repetition of basic techniques.
Originality/value: The article offers a novel comparison of VR and AR in the context of welding, based on evaluations from experienced welders rather than novices. It also integrates the TWI Job Instruction method into both training environments, providing a standardized instructional foundation for fair comparison and improved consistency.
Keywords: Welding training; Virtual Reality; Augmented Reality; Safety; Training Within Industry (TWI); Job Instruction; Skill transfer; Industrial training.
Category of the paper: Research paper.

Introduction

Welding is a fundamental industrial process used to join metal components in sectors ranging from construction and manufacturing to shipbuilding and automotive production (Kumar, Dharanipriya, 2014). It involves fusing materials by applying intense heat and sometimes pressure, often creating an electrical arc that can reach temperatures over 5000°C. The very nature of welding makes it one of the most dangerous technical occupations. Operators are routinely exposed to multiple hazards (Mozzoni et al., 2020; Pirvu et al., 2024): extreme heat and bright ultraviolet light from the welding arc, electrical currents, hazardous fumes and gases. Common injuries among welders include skin burns, eye injuries (corneal flash burns, cataracts), hearing loss, metal fume fever, and acute pneumonia (Bayram et al., 2016; Mozzoni et al., 2020; Ahn et al., 2023).

Given these risks, ensuring welders are thoroughly trained in safe practices is paramount. Traditional welding instruction often involves hands-on practice with real equipment, which itself carries intrinsic dangers and significant costs (Carter et al., 2006; Christian et al., 2009). Novice welders learning on actual workpieces risk injuring themselves or others and can damage expensive materials or tools due to mistakes. Conventional training also incurs high material consumption (metal coupons, electrodes, gas) and requires experienced instructors to physically supervise each trainee (Pribadi et al., 2024). Technology-enhanced training has emerged to fill this need. In particular, Virtual Reality (VR) and Augmented Reality (AR) systems allow trainees to practice welding in simulated environments that eliminate physical danger while providing realistic feedback (Pribadi et al., 2024; Alfaro-Viquez et al., 2025). VR immerses the user completely in a computer-generated world. AR overlays digital simulations onto the user's view of the real world, permitting training with real tools and objects enhanced by virtual guidance or feedback.

This article compares VR and AR training systems deployed at an Educational Laboratory in the Walbrzych Special Economic Zone, focusing on their effectiveness in mirroring real welding conditions and improving operator readiness. We hypothesize that AR, which allows interaction with physical tools and the real environment, will provide a stronger sense of realism and skill fidelity than VR.

Literature Review

VR-based training can significantly reduce workplace accidents by allowing workers to experience and learn from simulated hazards in a safe setting (Mozzoni et al., 2020). In construction safety studies, trainees who practiced in immersive VR environments

demonstrated better hazard recognition and safety compliance compared to those with traditional training (Sacks et al., 2013; Stefan et al., 2023). VR also enables unlimited repetition of scenarios, crucial for mastering high-risk skills like welding (Alfaro-Viquez et al., 2025). However, research suggests that the effectiveness of VR/AR training depends on how closely the simulation matches real tasks. Realism and skill transfer are key: the closer the training experience is to actual welding, the more likely skills will transfer to real operations (Pribadi et al., 2024; Alfaro-Viquez et al., 2025). A systematic review of 136 studies concluded that VR is broadly effective for safety and technical skills training, especially when evaluations show improved learning and user engagement (Stefan et al., 2023; Chan et al., 2022). AR supports situated learning and may outperform VR when physical manipulation is essential. It has been shown to produce equal or better student outcomes than traditional training while significantly lowering material use (Michalak et al., 2024). In ergonomic and procedural tasks, AR results in higher task accuracy and shorter learning times than VR (Ai et al., 2024; Liu et al., 2022). Users often report that AR feels more like "the real thing" because they can manipulate tangible items, unlike VR which lacks physical cues (Pribadi et al., 2024).

An important but often overlooked factor in simulation-based training is the consistency and structure of the instructional content. The Training Within Industry (TWI) Job Instruction method has been recognized for its ability to standardize and improve workplace training (Dinero, 2005). TWI emphasizes breaking down a task into clearly defined steps, key points, and underlying reasons, ensuring trainees receive uniform and high-quality instruction (Misiurek, 2016; Misiurek, Misiurek, 2017). Studies show that applying TWI improves employee competence and reduces training variability, which is particularly relevant in high-risk contexts like welding (Wrona, Graupp, 2006). Despite its proven effectiveness, the integration of TWI into VR/AR training programs remains underexplored, presenting an opportunity to enhance the structure and efficacy of immersive training solutions.

Methods

1. Participants

We invited 40 certified welders participated in the study. All held welding certifications (at least European or AWS Certified Welder status) and had a minimum of 5 years of field experience. This experienced group was selected to ensure informed assessments of training realism.

2. Equipment and Procedure

Each participant trained on both VR and AR systems by completing a standard bead-on-plate welding task in each modality. The sessions took place in a controlled lab setting. VR immerses the trainee in a fully synthetic environment, blocking out the physical world

entirely. In our laboratory's VR welding simulator, the user wears a head-mounted display that presents a 3D virtual workshop containing welding equipment and workpieces (Figure 1). The trainee also uses input devices – in this case, a realistic mock welding torch and a sensor-tracked glove or controller – to interact with the virtual environment. As the user "welds" in VR, the system simulates the visual and auditory feedback of welding: one sees a virtual arc, melting weld pool, and sparks, and hears the crackle of the weld. The VR simulator can also provide guidance and performance feedback, for example by overlaying indicators for proper torch angle or travel speed during the simulation.

Figure 1. VR welding simulator in Walbrzych Special Economic Zone.

Source: Authors' own creation.

A major benefit of VR is safety – trainees can make mistakes (like improper angle or contact) with no risk of injury or damage (Alfaro-Viquez et al., 2025). VR also allows exercises that would be difficult or costly in reality, such as repeatedly welding the same joint type under identical conditions to practice consistency (Wells, Miller, 2020). Studies have shown that VR training can improve learners' focus and reduce distractions since the immersive experience captures their full attention (Pribadi et al., 2024; Stefan et al., 2023). On the downside, current VR technology has limitations in realism. Trainees do not feel the true weight of welding apparatus or the heat of the arc. The absence of physical forces and haptic cues can make some actions (like gauging proper electrode distance or applying correct force) less intuitive.

Furthermore, some users experience simulator sickness (motion dizziness or discomfort) in VR, especially during longer sessions (Pribadi et al., 2024). Despite these drawbacks, VR's ability to simulate hazardous scenarios without real danger makes it a powerful training tool (Mozzoni et al., 2020).

AR offers a different approach – instead of replacing reality, it augments the real-world environment with virtual elements (Pribadi et al., 2024). In our AR training system, the trainee wears a see-through AR welding helmet that overlays digital information onto their view of an actual welding station (Figure 2). The trainee holds a real or replica welding torch, and there is typically a physical workpiece (or coupon) in front of them.

Figure 2. AR welding simulator in Walbrzych Special Economic Zone.
Source: Authors' own creation.

When the trainee strikes an arc or makes a weld bead in AR, there is no real electric arc; instead, the system superimposes a virtual arc and weld onto the physical workpiece as seen through the AR display. Essentially, the user sees the real nozzle of their torch and the real metal piece, with computer-generated graphics adding the molten weld puddle, sparks, smoke, and other visual cues in correct position. In our lab's AR setup, for example, trainees practiced bead-on-plate welding on a metal coupon while the AR helmet projected a realistic molten weld pool and feedback indicators onto that coupon. The key advantage of AR is the blend of physical and virtual: because the trainee holds a real torch and works with real objects (albeit unpowered), the kinaesthetic and ergonomic aspects of welding are preserved. The weight of the torch, the need to brace oneself against a workbench, and the spatial orientation to a real workpiece all mirror actual welding conditions. This physical fidelity can enhance the sense of realism – indeed, users often report that AR feels more like "the real thing" because they can

directly see and manipulate tangible items rather than only virtual representations (Alfaro-Viquez et al., 2025; Pribadi et al., 2024).

Despite these challenges, AR's ability to allow hands-on practice with real equipment under guided virtual visualization makes it extremely promising for welding education (Michalak et al., 2024). For instance, an augmented reality welding simulator was shown to produce equal or better student outcomes than traditional training, while significantly lowering material use.

VR and AR differ fundamentally in the level of immersion and the role of physical context (Pribadi et al., 2024). VR offers total immersion – useful for training scenarios like out-of-position welds or dangerous situations (e.g. welding at heights or in confined spaces) that can be simulated virtually without risk. It also allows trainees to practice endlessly without consuming real consumables, thus is cost-effective for repetitive skill drills (Pribadi et al., 2024). AR, on the other hand, provides situated learning – the trainee practices in a setting closer to the actual work environment, which can improve their muscle memory and spatial awareness for real welding tasks. Our VR simulator in Poland was often used to teach novices basic techniques (arc striking, steady travel, proper angle) in a straightforward scenario, leveraging VR's interactive guidance. The AR system was then used to bridge the gap to live welding by having trainees perform those techniques on real hardware with augmented feedback. Notably, Ai et al. (2024) found in a controlled experiment that while both VR and AR enhanced training outcomes, VR users experienced more simulator sickness, and AR users reported greater comfort with the tasks. This suggests AR might be preferable for longer practice sessions where sustaining user comfort is important. Another study observed that AR training produced higher task accuracy and shorter learning times than a comparable VR training for certain procedural tasks (Alfaro-Viquez et al., 2025).

These findings reflect our own anecdotal experience with the welding trainees: those using the AR system tended to comment on how "real" it felt to hold the actual welding torch and see it in their hands, whereas those using VR appreciated the fully immersive experience but noted it was "like a video game" and lacked the physical cues of welding.

3. Survey Instrument

After the sessions, participants completed a Likert-scale questionnaire. The key statement was: "The training felt realistic compared to actual welding". Ratings ranged from 1 (Strongly Disagree) to 5 (Strongly Agree). Since each participant evaluated both the VR and AR training systems, the two sets of scores are dependent. Therefore, a paired samples t-test (dependent samples t-test) was applied to assess whether the perceived realism differed significantly between the two modalities.

4. Instructional Design

To maximize the effectiveness of both the VR and AR training platforms, we integrated a structured instructional design based on the Training Within Industry (TWI) Job Instruction (JI) method. TWI JI is a proven methodology dating back to the 1940s that emphasizes breaking down jobs into well-defined steps, important key points, and rationale reasons in order to train

workers quickly and consistently (Misiurek, Misiurek, 2017). This approach was originally developed to rapidly upskill industrial workers during World War II, and it remains highly relevant for training in complex or dangerous tasks like welding (Wrona, Graupp, 2006).

We created a step-by-step welding instruction guide following TWI principles for a basic welding task for VR welding operation (Figure 3) and AR welding operation (Figure 4). These instructions were then embedded into the training systems: in the VR simulator, a tutorial mode leads the trainee through each step with prompts and highlights. In the AR system, instructions can be shown on the heads-up display – for instance, an arrow might appear on the workpiece indicating where to start. In addition, a trainer in the lab can use the TWI guide as a lesson plan when supervising trainees on either system, to ensure consistent messaging.

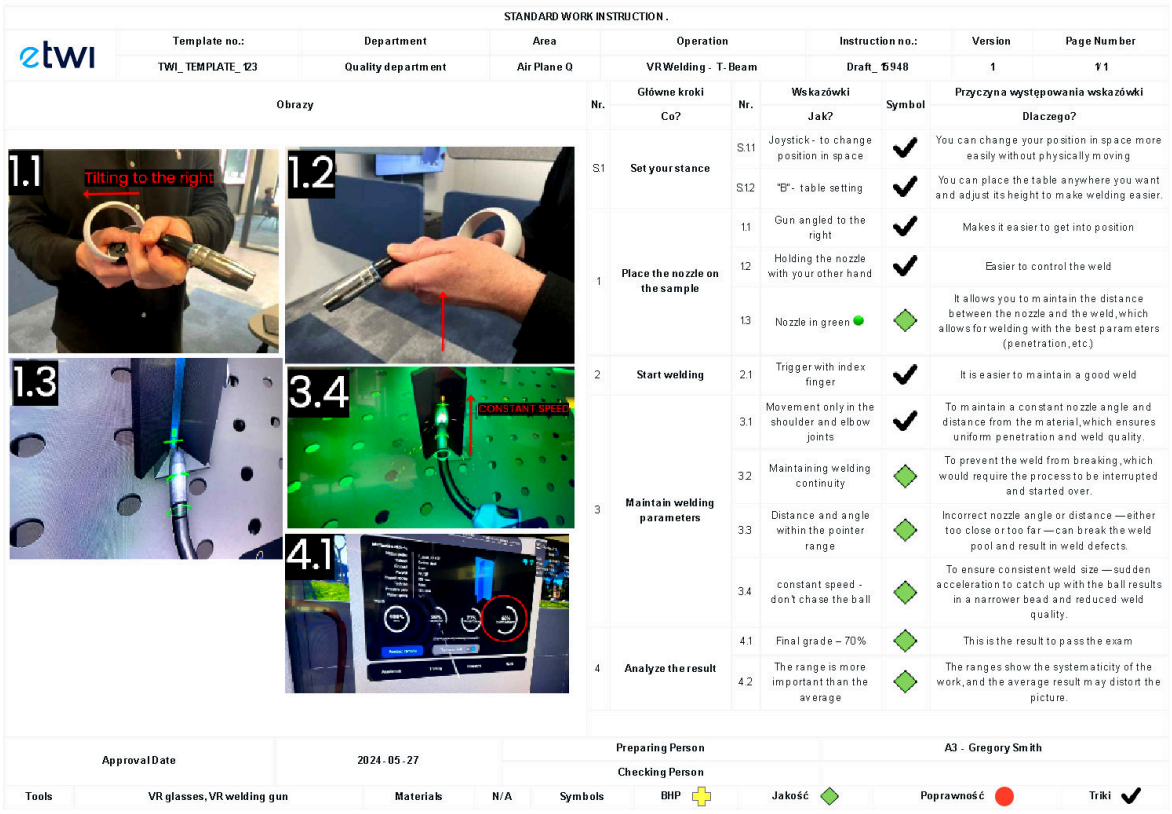

Figure 3. Work instruction for VR welding operation.

Source: Authors' own creation.

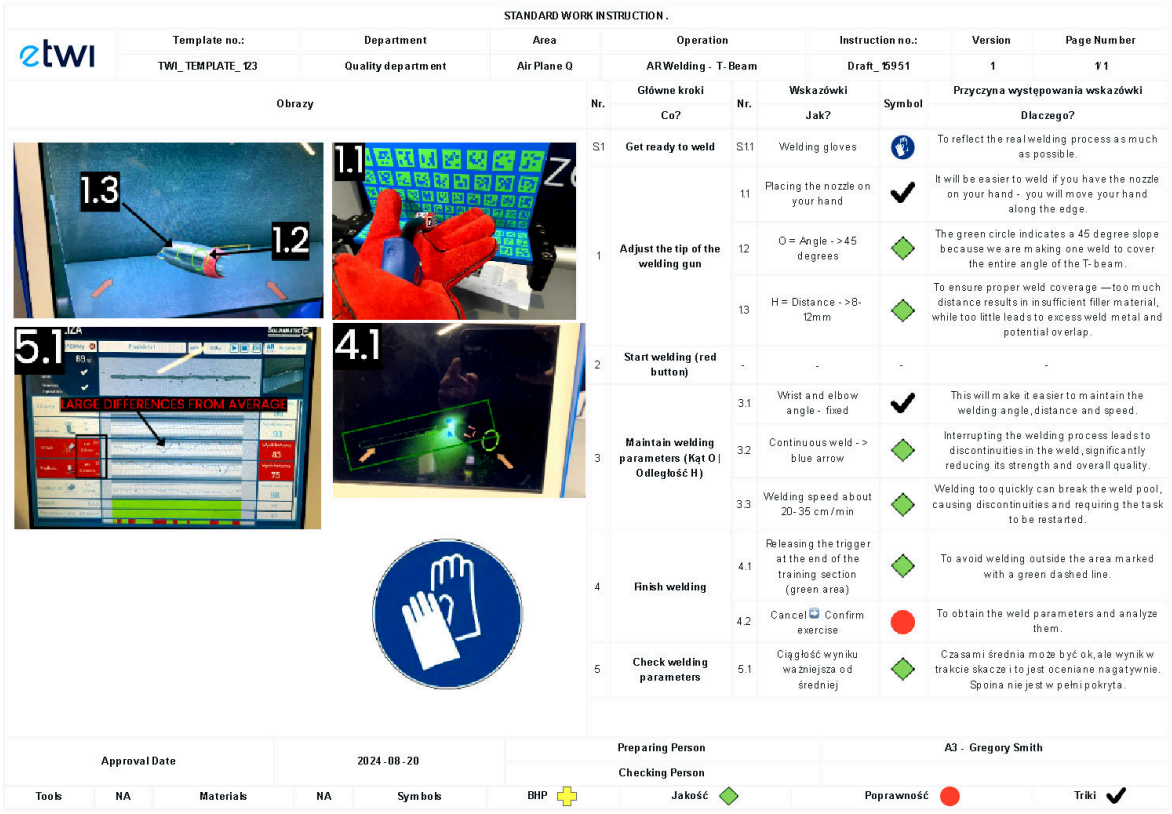

Figure 4. Work instruction for AR welding operation.

Source: Authors' own creation.

The use of TWI JI brings a formalized pedagogy to VR/AR training, which might otherwise be used in an ad-hoc way (Dinero, 2011). By standardizing the training procedure, we aimed to eliminate any ambiguity for the trainees – each technology delivers the same fundamental instruction content (Misiurek, 2016). The TWI method is well-known for its ability to improve workplace safety and product quality through better training. Its mantra is "If the worker hasn't learned, the instructor hasn't taught," emphasizing instructor responsibility in skill transfer. In a study on construction industry safety, Misiurek and Misiurek (2017) applied TWI-based training and found it significantly reduced human errors contributing to accidents. They note that the TWI program focuses on improving employees' skills to perfect their work rather than simply raising productivity – a philosophy that aligns closely with welding training, where doing the job correctly and safely is the top priority.

By using a Job Instruction breakdown for welding, we ensure that trainees not only know what to do, but why each step is important (for example, why a certain travel speed is necessary to avoid weld defects, or why eye protection must be worn even in simulations). Even in the virtual environment, safety protocols were reinforced – the VR simulation, for instance, requires the trainee to virtually "put on" safety gear before welding (simulated via an equipment checklist), and the AR trainer likewise begins each session reminding about proper helmet use and ventilation (even though no actual fumes are produced, the habit is instilled). Such elements reflect the TWI philosophy of building correct habits and awareness.

By explicitly applying the TWI Job Instruction method, our training program seeks to eliminate variability in training quality between VR and AR. Both systems convey the same "one best way" to perform the weld, ensuring that any differences in outcomes between VR and AR can be attributed to the medium (e.g., the presence of physical cues in AR) rather than differences in instructional content. This strengthens the fairness of our VR-vs-AR comparison.

Results

AR received an average realism score of 4.13/5. VR received 2.55/5. The comparison of these scores is illustrated in Figure 5. The difference of 1.58 points was statistically significant ($p < 0.001$). Participants praised AR for physical realism: real tools, spatial orientation, depth perception, and tactile feedback. In AR, users could rest their hands, brace against surfaces, and view the weld through a helmet, replicating actual welding postures. an average realism score of 4.13/5. VR received 2.55/5. The difference of 1.58 points was statistically significant ($p < 0.001$). Participants praised AR for physical realism: real tools, spatial orientation, depth perception, and tactile feedback. In AR, users could rest their hands, brace against surfaces, and view the weld through a helmet, replicating actual welding postures.

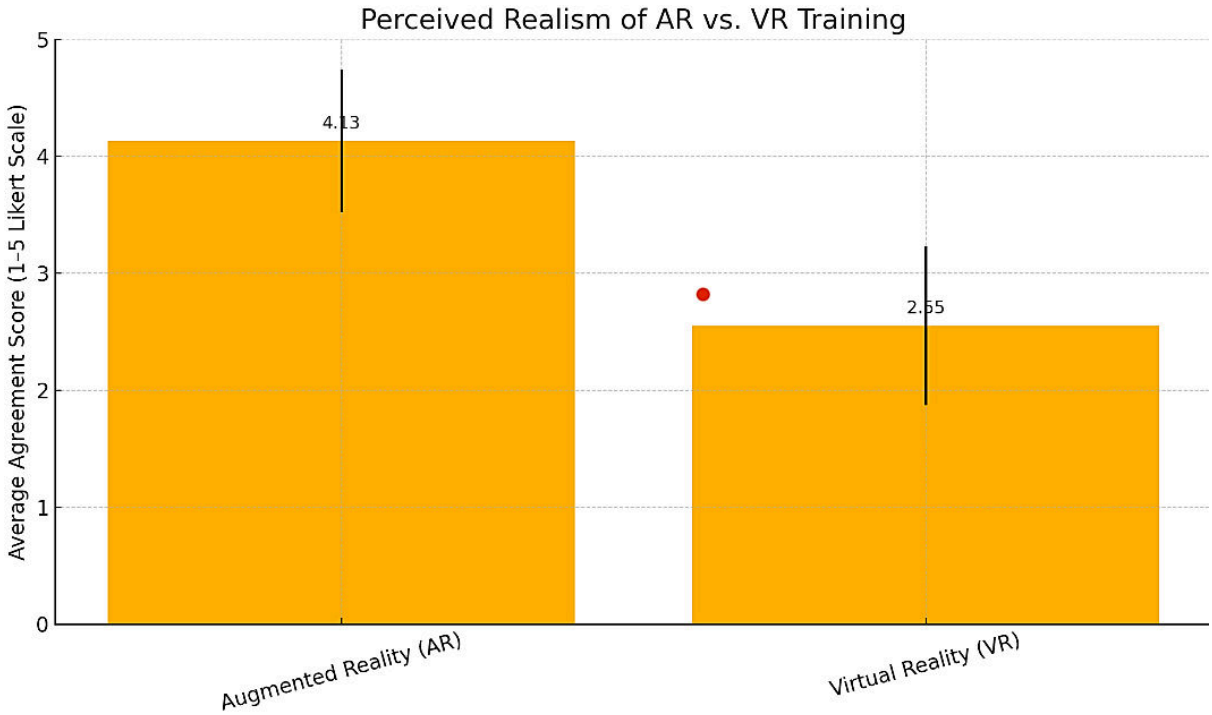

Figure 5. Comparison of the average ratings for VR and AR realism rating.

Source: Authors' own creation.

In contrast, VR was described as immersive but less authentic. Participants noted the absence of real resistance and reference points. Some attempted to lean on virtual tables and were surprised by the lack of feedback. VR's visuals, while clear, lacked the blinding arc brightness of real welding. Simulated audio and visual cues felt more like a training video game. Nevertheless, VR was valued for novice instruction. Participants appreciated its safety, repeatability, and guided practice. It allowed them to repeat fundamental techniques (e.g. torch angle, arc length) in a controlled space (Mozzoni et al., 2020; Roundtable Learning, 2023). These findings align with prior research suggesting that AR better supports skill transfer through physical fidelity and contextual interaction (Chan et al., 2022; Ai et al., 2024).

Discussion

It is worth noting that these ratings are subjective and pertain to perceived realism, which we use as a proxy for potential training effectiveness – the assumption being that training which feels more like real work will better prepare the trainee. We did not measure actual welding skill improvement in this survey – that is, we did not have participants perform real welds after training to assess skill transfer quantitatively. However, literature suggests a strong correlation between simulation realism and skill transfer in psychomotor tasks. Chan et al. (2022) emphasize that VR/AR welding trainers should mimic real-world welding conditions closely to effectively build psychomotor skills. Our findings align with that view: the AR system's physical interaction (real torch, real posture) likely contributed to a higher sense of realism and thus may yield better skill transfer.

Participants' comments provided insight into why AR felt more authentic. Many welders highlighted the importance of depth perception and hand-eye coordination with actual objects. In AR, they could physically touch the workpiece with the torch (the torch had an inert tip), and this tactile contact is exactly what they do to maintain arc length in reality (resting the cup or using distance feel). In VR, by contrast, if they tried to prop their hand on a table or lean on the workbench for stability, they found nothing solid (some actually tried and were surprised when their hand "went through" the virtual table). This lack of tangible reference points in VR was disorienting for some. Also, in AR they wore an actual welding helmet with the AR visor, which mimicked the constrained view through a real welding filter, whereas in VR the view was broader and not exactly like looking through a welding mask.

Furthermore, lighting and spatial awareness differed: AR trainees worked in the actual room lighting (with the augmented arc appearing bright), allowing their eyes to behave normally; VR had to simulate the lighting and some noted it wasn't as blinding as a true weld (to avoid discomfort, VR often tones down the brightness). Welders are used to a certain way the arc light affects their vision, so AR's handling of that (since it overlays a realistic glare effect) impressed

them as more true-to-life. Despite AR's clear advantage in realism, our survey also underscored some positive aspects of VR. A number of participants acknowledged that VR would be excellent for initial practice and training novices.

In summary, the survey results strongly favored AR over VR in terms of experiential realism for welding training. This finding is consistent with prior observations in other domains: for example, Ai et al. (2024) found AR better suited than VR when actual body coordination was important, due to less simulator sickness and better user comfort. Similarly, in maintenance training, researchers have reported shorter task completion times and higher accuracy with AR instruction compared to screen-based or VR training (Liu et al., 2022). Our study adds specific evidence from the welding domain: experienced practitioners clearly recognize the added value of AR in replicating the feel of welding.

Conclusions

This study compared Virtual Reality (VR) and Augmented Reality (AR) in welding training, focusing on how realistically each method replicates real-world conditions. Welding is a high-risk process, traditionally requiring supervised hands-on instruction (Mozzoni et al., 2020; Pirvu et al., 2024). VR and AR offer safer alternatives by eliminating exposure to actual hazards (Pribadi et al., 2024). Our survey of 40 certified welders revealed a clear preference for AR, which achieved a realism rating of 4.13/5, compared to VR's 2.55/5 – a statistically significant difference. Respondents cited AR's use of real tools, physical posture, and tactile interaction as key factors that enhanced its realism (Alfaro-Viquez et al., 2025; Chan et al., 2022). In contrast, VR's lack of haptic feedback and physical reference points made it feel less authentic, although its safety and guided practice features were appreciated. Both systems have complementary strengths: VR excels in early-stage training, allowing for unlimited repetition and controlled environments; AR supports skill transfer through physical fidelity and context. Organizations should consider combining both approaches—starting novices in VR, then transitioning them to AR.

Future research should include quantitative skill transfer assessments and explore innovations like haptic VR feedback and multi-user AR systems. Recent findings suggest AR can reduce training costs without compromising effectiveness (Michalak et al., 2024). AR proved more realistic and effective for experienced welders, while VR remains valuable for foundational learning. Their integration—supported by structured methods like TWI—represents a forward-looking model for industrial skills training in the era of Industry 4.0 and 5.0 (Alfaro-Viquez et al., 2025).

References

1. Ahn, J., Park, J.Y., Lee, S.S., Lee, K.H., Do, H., Ko, J.G. (2023). SafeFac: Video-based smart safety monitoring for preventing industrial work accidents. *Expert Systems with Applications, 215,* 119397. https://doi.org/10.1016/j.eswa.2022.119397.
2. Ai, X., Santamaria, V., Agrawal, S.K. (2024). Characterizing the Effects of Adding Virtual and Augmented Reality in Robot-Assisted Training. *IEEE Transactions on Neural Systems and Rehabilitation Engineering, 32,* 2709-2718. DOI: 10.1109/TNSRE.2024.3432661.
3. Alfaro-Viquez, D., Zamora-Hernandez, M., Fernandez-Vega, M., Garcia-Rodriguez, J., Azorin-Lopez, J. (2025). Integrating Virtual Reality into Welding Training: An Industry 5.0 Approach. *Electronics, 14(10),* 1964. DOI: 10.3390/electronics14101964.
4. Bayram, M., Ünğan, M.C., Ardıç, K. (2016). The relationships between OHS prevention costs, safety performance, employee satisfaction and accident costs. *International Journal of Occupational Safety and Ergonomics, Vol. 23, Iss. 2.* https://doi.org/10.1080/10803548.2016.1226607.
5. Carter, G., Smith, S.D. (2006). Safety hazard identification on construction projects. *Journal of Construction Engineering and Management, 132(2),* 197-205. http://dx.doi.org/10.1061/(ASCE)0733-9364(2006)132:2(197).
6. Chan, V.S., Haron, H.N.H., Isham, M.I.B.M., Mohamed, F. (2022). VR and AR virtual welding for psychomotor skills: a systematic review. *Multimedia Tools and Applications, 81(9)*, 12459-12493. DOI: 10.1007/s11042-022-12293-5.
7. Christian, M.S., Bradley, J.C., Wallace, J.C., Burke, M.J. (2009). Workplace safety: a meta-analysis of the roles of person and situation factors. *Journal of Applied Psychology, 94(5),* 1103-27. http://dx.doi.org/10.1037/a0016172.
8. Dinero, D. (2005). *Training Within Industry: The Foundation Of Lean*. Productivity Press, 229, 238, 244-250. https://doi.org/10.1201/b18692.
9. Dinero, D. (2011). *TWI Case Studies. Standard Work, Continuous Improvement and Teamwork.* Productivity Press, p. xiii. https://doi.org/10.4324/9781439891247.
10. Kumar, S.G., Dharanipriya, A. (2014). Prevalence and pattern of occupational injuries at workplace among welders in coastal South India. *Indian Journal of Occupational and Environmental Medicine, 18(3),* 135-139. DOI: 10.4103/0019-5278.146911.
11. Liu, X.-W., Li, C.-Y., Dang, S., Wang, W., Qu, J., Chen, T., Wang, Q.-L. (2022). Research on training effectiveness of professional maintenance personnel based on virtual reality and augmented reality technology. *Sustainability, 14(21),* 14351. DOI: 10.3390/su142114351.
12. Michalak, D., Rozmus, M., Tokarczyk, J., Szewerda, K. (2024). Portable VR Welding Simulator. *Applied Sciences, 14(17),* 7687. DOI: 10.3390/app14177687.

13. Misiurek, B. (2016). *Standardized Work with TWI: Eliminating Human Errors in Production and Service Processes*. New York: Productivity Press, https://doi.org/10.1201/b19696.
14. Misiurek, K., Misiurek, B. (2017). Methodology of improving occupational safety in the construction industry on the basis of the TWI program. *Safety Science, 92*, 225-231. DOI: 10.1016/j.ssci.2016.10.017.
15. Mozzoni, P., Cavallo, D., Corradi, M., Riccelli, M.G., Goldoni, M., Poli, D. (2020). Welding Fumes, a Risk Factor for Lung Diseases. *International Journal of Environmental Research and Public Health, 17(7)*, 2552. DOI: 10.3390/ijerph17072552.
16. Pirvu, V., Rontescu, C., Bogatu, A., Cicic, D., Burlacu, A., Ionescu, N. (2024). Research on Occupational Risk Assessment for Welder Occupation in Romania. *Processes, 12(7),* 1295. DOI: 10.3390/pr12071295.
17. Pribadi, A.P., Rahman, Y.M.R., Silalahi, C.D.A.B. (2024). Analysis of the effectiveness and user experience of employing virtual reality to enhance the efficacy of occupational safety and health learning for electrical workers and graduate students. *Heliyon, 10(15),* e034918. DOI: 10.1016/j.heliyon.2024.e34918.
18. Roundtable Learning (2023). *9 Examples of Safety Training in VR. Roundtable Learning*. Available at: https://roundtablelearning.com/9-examples-of-safety-training-in-vr, 17 May 2025.
19. Sacks, R., Perlman, A., Barak, R. (2013). Construction safety training using immersive virtual reality. *Construction Management and Economics, 31(9),* 1005-1017. DOI: 10.1080/01446193.2013.828844.
20. Stefan, H., Mortimer, M., Horan, B. (2023). Evaluating the effectiveness of virtual reality for safety-relevant training: a systematic review. *Virtual Reality, 27*, 2839-2869. DOI: 10.1007/s10055-023-00843-7.
21. Wells, T., Miller, G. (2020). The Effect of Virtual Reality Technology on Welding Skill Performance. *Journal of Agricultural Education, 61(1),* 152-171. DOI: 10.5032/jae.2020.01152
22. Wrona, B., Graupp, P. (2006). *The Twi Workbook: Essential Skills for Supervisors*. New York: Productivity Press. https://doi.org/10.1201/b19661.

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IMPACT OF AIRPORT INFRASTRUCTURE DEVELOPMENT IN GDAŃSK: EX-POST ANALYSIS

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*Correspondence author

Purpose: The purpose of this paper is to assess the effectiveness and long-term impact of infrastructure investments implemented at Gdańsk Lech Wałęsa Airport between 2010 and 2015. The study evaluates whether the planned operational capacity was achieved and explores the socio-economic and environmental effects on the surrounding region.
Design/methodology/approach: An ex-post evaluation approach was applied, combining quantitative and qualitative data analysis. Airport performance indicators such as passenger traffic, runway operations, and financial stability were examined alongside spatial and demographic data from neighbouring areas. The research is grounded in regional growth theory and sustainable infrastructure frameworks and incorporates elements of cost-benefit assessment.
Findings: The findings confirm that the main objectives of the investment were fulfilled. The airport exceeded the 5-million-passenger threshold in 2019, validating the expansion strategy. Technical enhancements (e.g., ILS CAT IIIb, increased hourly operations) and improved connectivity supported job creation, land value growth, and urban development. However, challenges such as transport congestion, spatial conflicts, and environmental pressures highlight the need for integrated spatial and infrastructure planning.
Research limitations/implications: The research is limited to pre-pandemic data and does not fully capture the long-term outcomes of newer investments. Future studies should examine post-COVID trends, climate resilience, and regional integration within EU transport policy.
Practical implications: The paper provides evidence-based insights for policy-makers and infrastructure managers, showing how airport development can support regional strategies and attract complementary investment. It underscores the need for aligning technical capacity with spatial policy and public service infrastructure.
Social implications: The investment improved accessibility and quality of life in the Tri-City region. However, it also exposed tensions in local planning and land-use policy. The study suggests that future infrastructure projects should ensure stronger public participation and environmental safeguards.
Originality/value: This paper offers a comprehensive ex-post evaluation of a major EU co-financed airport project in Central Europe. It demonstrates the catalytic role of airport infrastructure in regional transformation and contributes empirical evidence relevant to development planning and policy implementation.

Keywords: airport infrastructure; regional development; sustainable transport, infrastructure, investment,
Category of the paper: research paper.

1. Introduction

The subject of subsequent editions of the World Bank's reports on the development of the world always concerns important determinants of this development. The report published in 1994 noted and emphasized the importance of infrastructure for the development of world regions and economies. The report shows that changes in the infrastructure have a positive effect on global economic growth, and an increase in infrastructure by 1% is compared to a GDP growth of 1%, and the mere expansion of the road network leads to an increase in GDP by 0.8% (World Development Report, 1994). This means that the condition of the economy may be positively stimulated by the implementation of infrastructure investments. Infrastructure investments are not only a stimulus, but also a factor conditioning the development of regions. There is a strong positive correlation between the level of socio-economic development of a region or a country and the degree of demand for infrastructure and the resulting services (Ratajczak, 2000, p. 86).

The article concerns investments in the development of the infrastructure of Gdańsk Lech Walesa Airport implemented in 2010-2015. The ex-post analysis aims to identify the effects in terms of benefits and costs for the airport and its surroundings. The study makes a research assumption that the investments made in 2010-2015 formed the basis for further development of the port and its surroundings. The study uses elements of cost-benefit analysis related to the identification of investment effects, in order to draw conclusions on the effectiveness of the undertaken investment activities.

Gdańsk Lech Wałęsa Airport was selected as the subject of this study due to: (1) its inclusion in the TEN-T network, (2) the highest traffic growth among regional airports in Poland during the analyzed period, (3) its significant economic and tourism-related importance for the Pomeranian region, and (4) the availability of financial and operational data.

The article presents a review of research on the impact of infrastructure development on the economic development of regions and the impact of infrastructure investments by airports on their development and on changes in their surroundings. The paper presents the effects of the implemented development investment in Gdańsk Lech Walesa Airport identified by the authors in the form of distinguishing the costs and benefits resulting from it for the port and its surroundings. Conclusions were presented at the final section of the paper.

2. Theoretical background and literature context

Paul Rosenstein-Rodan, co-founder of the development economics, in his research focused on the economic growth of middle- and underdeveloped countries. As the creator of the concept of „big push", he believed that after exceeding a certain threshold of development, the economies of the poorer regions are able to still develop on their own. To exceed this threshold, external economic aid is needed, including, among others, support for the implementation of infrastructure investments and industrialization of regions (Rosenstein-Rodan, 1959, pp. 360-369; Rosenstein-Rodan, 1976). For Poland, which joined the community of European Union Member States in 2004, European funds aimed at the development of Poland's infrastructure have been the effect of the „big push".

Infrastructure investments are recognized by many economists as a factor of growth and development of the region, therefore they also appear in numerous other theories, concepts and economic models, such as: Harrod-Domar model, Solow growth theory, Romer's, Barro and Sala-i-Martin's, Lucas's endogenous growth theories, Aschauer's theory of endogenous development, as well as Biehl's concept of endogenous regional development (Barro, Sala-i-Martin, 2003; Romer, 1986, pp. 1002-1037; Solow, 1956, pp. 65-94; Lucas, 1988, pp. 3-42; Dunford, 2009, pp. 192-201). Polish researchers also emphasize the importance of infrastructure investments in the development of enterprises and regions (Parysek, 2001; Ratajczak, 2000). Infrastructure is considered by some to be one of the key and, at the same time, the most effective factors determining development due to its functions and unique features (Dolata, 2015, p. 46).

In the literature, infrastructure investments are considered in terms of sustainable development, how the goal of sustainability is used in a case of transport infrastructure investment, because this kind of investment raises serious questions about the sustainability of all the three areas mentioned: economy, ecology, and democracy. This kind of investment exceeds the local and regional levels by many times, not least when it comes to its environmental consequences and its economic benefits (Lidskog, Soneryd, 2000, p. 1465).

Investments made by airports are discussed in the literature in terms of their effects on the region. At the beginning of the second half of the twentieth century, this problem was addressed, among others, by William. F. Ogburn (1946, pp. 373-379) by studying the interactions of the development of air transport and spatial structures and by Joachim H. Schultze (1959, pp. 1-202) studying the impact of air transport and its infrastructure on the development of urban agglomerations.

Researchers also draw attention to the aspect of financing sources of infrastructure investments, including airport investments (Forsyth, 2018, p. 259; Wojewnik-Filipkowska, 2008, p. 160). Due to the high capital intensity of airport infrastructure investments, the along period of the investment process and the high risk, such investments often cannot be

implemented solely with the use of private investors' capital, but require external support or other solutions[1].

3. Research methodology

The subject of the research is an investment financed partially from the European Union funds. There are guidelines that you need to pay special attention to when developing a need for a transport investment. These include, among others, demographic changes; socio-economic changes, including GDP level in analysed area, income and the level of unemployment; industrial and logistic structure and developments: location of concentrated industrial activities, natural resources, main transport hubs (ports and airports), logistics structure, spatial changes, traffic volume, etc. (UE Guide, 2014, p. 81). The guide presents the costs and benefits of a planned investment. On the other hand, this article identifies the costs and benefits of the implemented airport investment.

The study was conducted in two areas. First, the effects of the implemented investment for the airport were identified. It was examined whether a sustained effect of the possibility of handling more passengers per year was achieved and whether the number of flight operations per hour increased. Moreover, the financial statements of Gdańsk Lech Walesa Airport were analysed and it was assessed whether the investment had an impact on its financial condition.

The second research area was the effects of the development of the airport in Gdańsk, noticeable in its close vicinity and in the region. Positive and negative effects in the socio-economic environment and for the natural environment (Atkinson et al., 2006) have been identified. These are elements belonging to the method referred to in the literature as cost-benefit analysis (Quinet, 2007).

The article is based on a variety of publicly accessible sources, including financial data retrieved from the ORBIS database, official websites of Gdańsk Lech Wałęsa Airport and the City of Gdańsk, as well as selected documents obtained directly from the airport administration and the Pomeranian Voivodeship Office in Gdańsk.

[1] The financing of such projects may vary, they may be funds obtained from prepayments. They are very often used by airports to fund major investments, such as runways and terminals. It involves the airport charging airlines higher prices as soon as, and sometimes before, the project's construction commences, often well before it becomes operational (Forsyth, 2018, p. 259). This form of financing is available for the higher rank airports. Those of lesser rank use traditional forms of financing and combine equity capital with borrowed capital. Public funds are also used, and in the case of member states - the EU funds.

4. Results & discussion

The study covered the area where the Gdańsk Airport is located. Gdańsk and neighbouring Gdynia are strategically important hubs belonging to the Trans-European Transport Network (TEN-T). Land, sea and air routes cross here. Currently, work is underway on two transport corridors crossing Poland: the Baltic-Adriatic Corridor and the North Sea - Baltic Corridor, both of which the port cities are part of. In a study the aim of which was to classify the main Polish cities, taking into account: factors of the size of an urban area (population, number of apartments, budget revenues, number of entities), factors of economic development and wealth of the urban area (budget revenues, number of entities, factors of inhabitants' wealth (unemployment rate, average salary), Gdańsk and Gdynia have been permanently classified into the wealthier cities' group (Kokot, 2021, p. 84). This paper analyses whether the effects of the development of an airport concern only the airport itself or are reflected in the development of the region.

The subject of the analysis are the effects resulting from the implementation of development investments in Gdańsk Lech Walesa Airport in 2010-2015. For this reason, the research period covers the years before and after the implementation of these investments.

Gdańsk Lech Walesa Airport started operating in 1974. After the political transformation in Poland, since 1993, the Gdańsk Airport has been operating as a commercial law company, the shareholders of which are local government units and State-owned company "Airports" (now Polish Airports State Company) (Table 1).

Table 1.
Current shareholders of Gdańsk Lech Walesa Airport

Shareholders	Shares (%)
Municipality of Gdańsk	37,33
Pomeranian Voivodeship	31,02
Polish Airports State Company	27,47
Municipality of Gdynia	2.11
Municipality of Sopot	2.07

Source: own elaboration based on information from the website https://www.airport.Gdańsk.pl/, 02.2025.

The condition of the infrastructure at the airport in Gdańsk in the 1990s was not sufficient. In 1997, the building of the Passenger Terminal 1 (T1) was put into use. In the following years, it was expanded, but it did not bring the desired results. The main limitations of the Gdańsk airport were the infrastructure elements on the airside and landside (Figure 1). These included in particular:

- no taxiway; the busy runway limited the port's capacity,
- insufficient apron space for airplanes,
- insufficient space for passenger service.

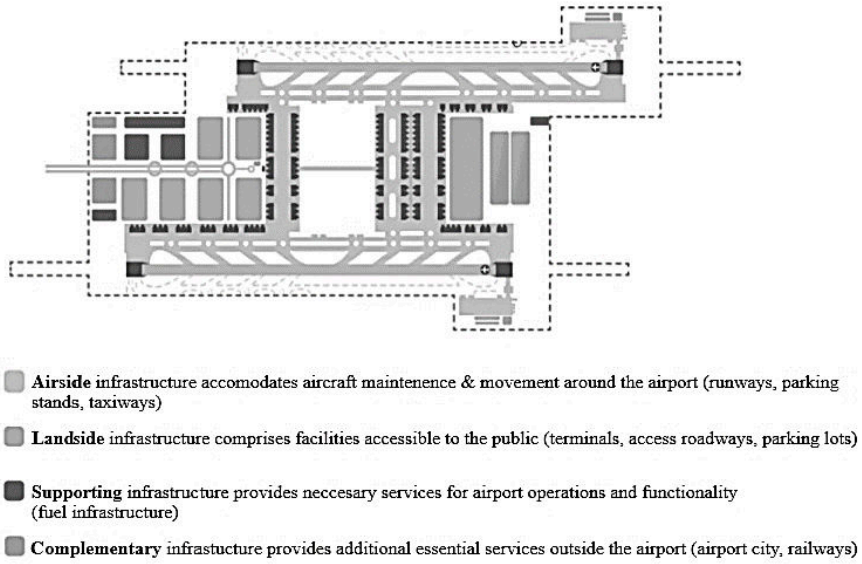

Figure 1. Typical airport infrastructure elements.

Source: Own elaboration based on information from the website https://www.cpk.pl/pl/dla-mieszkancow/program-lotniskowy/infrastruktura-lotniskowa: 15.12.2024.

As a result of the „big push", Gdańsk Lech Walesa Airport became the beneficiary of the EU funds. It was included in the TEN-T program and received funds for a needs analysis, and then obtained EU funds under the project "Studies on the long-term adjustment of the International Gdańsk Lech Walesa Airport, a TEN-T node in the North Poland, for air transport needs "- 2008-PL-92005-S. Additionally, the largest development of airport infrastructure took place before the UEFA European Football Championship in 2012 in Poland and Ukraine. These events led to the development of aviation infrastructure in Gdańsk and in other cities where football matches were held (Macioszek, 2021, p. 137). As part of the project, the objective was to increase the capacity of flight operations initially from 15 per hour to 45, then the expectations were reduced to 30 flight operations per hour; and to provide an airside and landside infrastructure capable of handling 5 million passengers a year (Table 2). The identification of investment needs was based on the location of Gdańsk Lech Walesa Airport, which plays an important role in the transport of business and tourist customers. It is also an important backup airport for Warsaw Chopin Airport.

Table 2.
Selected improvements of Gdańsk Lech Walesa Airport in 2005 and the prospects for 2012 from the perspective of year 2005

Subject of improvement	2005	2012
Runway dimensions	2800 m x 45 m	2800 m x 45 m
Runway capacity	15 operations/h	45 operations/h
Usable area	7260 m^2	50 424 m^2
Commerical area	1200 m^2	7500 m^2
Cubature	38 500 m^3	350 768 m^3
Passenger capacity	3 000 000	5 000 000

Source: Own elaboration based on documents from Gdańsk Lech Walesa Airport and data from "Studies on the long-term adjustment of the International Gdańsk Lech Walesa Airport, a TEN-T node in the North Poland, for air transport needs" - 2008-PL-92005-S.

The first of the planned development phases of Gdańsk Airport was implemented in 2010-2015 and included the following elements of the airport infrastructure:

- airport electric power system modernization,
- rainwater drainage system,
- noise monitoring system,
- taxiway,
- technical and patrolling road,
- technical base for airport equipment,
- apron,
- de-icing apron,
- new passenger terminal T2,
- office building for Customs Office and Border Patrol,
- others.

The effects of the investments of the airport are directed to increasing the efficiency of its operations. However, the components of the airport do not include only the elements listed in Figure 1. The literature also identifies intangible components of an airport, which include, among others, an external factor - environment (Urfer, Weinert, 2011, p. 112).

5. Effects for the airport

When analyzing the activities of airports, in the literature on the subject of the aviation sector, they are more and more often recognized as enterprises. This is because airports from the links of air transport infrastructure began to be perceived as economic entities, with the purpose of generating value for stakeholders. However, the airport management is obliged to ensure the airport is fully operational in compliance with the legal requirements, under the public service obligation, in accordance with the aviation law act.

The airport generates revenues from its basic activity, consisting in servicing air traffic (passenger and cargo) and on economic activity in the segments facilitating the efficient functioning of this traffic, as well as other complementary ones. The additional revenues generated in connection with servicing the passenger traffic are: shops, gastronomy, etc.

Table 3 presents the port's financial results achieved during and after the implementation of the development investment in 2010-2015. It covers the years 2014-2023, data from the earlier period are not publicly available.

Table 3.
Financial data of the Gdańsk Lech Walesa Airport in 2014-2023 (th EUR)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Exchange rate: PLN/EUR	0,2349	0,2355	0,2270	0,2395	0,2323	0,2344	0,2168	0,2175	0,2130	0,2300
Total assets	130 096	151 303	147 168	152 642	149 624	154 390	137 365	179 159	189 174	197 952
Operating revenue (Turnover)	31 974	33 888	34 150	40 682	45 745	49 813	25 070	25 426	41 917	60 204
Sales	28 443	30 413	31 084	36 054	41 769	46 483	18 209	21 958	39 820	56 103
Operating profit (loss) (EBIT)	8 681	7 427	7 583	8 840	3 191	14 638	556	-117	7 817	13 361
Profit (loss) for the period (Net income)	6 678	5 716	5 491	6 886	-2 640	11 262	-4	-530	4 524	9 711
Costs of employees	4 025	4 257	4 069	4 954	5 379	5 927	4 820	4 946	5 590	7 256
Depreciation & Amortization	7 326	7 839	8 802	9 879	9 552	9 679	8 869	7 649	9 014	11 480
Cash flow (Net Income before D&A)	14 003	13 555	14 293	16 764	6 913	20 941	8 864	7 120	13 538	21 190

*Local GAAP - ang. Generally Accepted Accounting Principles.

Source: Own elaboration based on ORBIS Database, https://ekrs.ms.gov.pl and information from Gdańsk Airport.

When analyzing the financial condition of the Gdańsk Airport company in the period after the implementation of the investment project in question, a positive trend in the development of the Gdańsk port can be observed. Revenues from sales are characterized by an upward trend in the subsequent years of the analysis, operating costs also increased. The financial analysis showed that data such as profit on operating activity and net profit doubled in value. These are good financial results that prove the positive impact of the implemented investments. In 2018, Gdańsk Airport recorded a loss of PLN 11 million for the first time, resulting from an unfavorable Court of Appeal in Gdańsk decision regarding the failure to provide service and warranty care by the construction consortium. Gdańsk Airport had to create provisions for a total value of PLN 42 million related to the court dispute. For the purposes of the profitability analysis, measured with indicators such as ROE, ROA and (Table 4), costs generated by legal disputes were excluded to correctly illustrate the company's condition.

Table 4.
Profitability ratios of the Gdańsk Lech Walesa Airport in 2014-2023

Profitability ratios (%)	2014	2015	2016	2017	2018	2019	2020 (pandemic year)	2021	2022	2023
ROE using Net income	10.64	8.33	7.66	8.35	-3.41	12.61	-0.01	-0.64	5.22	9.39
ROA using Net income	5,13	3.78	3.73	4.51	-1.76	7.30	0.00	-0.30	2.39	4.91
Cash flow/Operating revenue	43.8	40.00	41.85	41.21	15.11	42.04	35.36	28.00	32.30	35.20

Source: own elaboration based on ORBIS Database.

An analysis of Gdańsk Airport's financial indicators for the years 2014-2023 reveals fluctuations in operational efficiency and profitability in response to both strategic developments (infrastructure expansion) and crisis events (the COVID-19 pandemic). Between 2014 and 2017, the Cash Flow to Operating Revenue ratio remained stable at a high level

(approximately 40%), indicating the airport's strong ability to generate cash from its core operations. Concurrently, ROA and ROE values ranged between 3.7-5.1% and 7.7-10.6%, respectively, reflecting moderate yet consistent profitability. In 2018, all key indicators deteriorated significantly. The Cash Flow to Operating Revenue ratio fell to 15.1%, while both ROA and ROE turned negative (ROA: -1.76%, ROE: -3.41%). This downturn was likely driven by increased investment expenditures related to infrastructure expansion, combined with declining operational efficiency. The year 2019 marked a notable recovery. All indicators reached their highest values in the analyzed period (ROE: 12.61%, ROA: 7.30%, Cash Flow to Operating Revenue: 42.04%), suggesting effective utilization of prior investments and a favorable market environment. The period from 2020 to 2021, directly affected by the COVID-19 pandemic, saw a dramatic financial downturn. Profitability dropped to near-zero or negative levels, and cash generation capability weakened (down to 28.0% in 2021). This decline reflected reduced passenger traffic and sustained operational costs under restricted airport operations. Starting in 2022, a gradual recovery became evident. Improvements in ROA (reaching 4.91% in 2023) and ROE (9.39%), along with an upward trend in the Cash Flow to Operating Revenue ratio (35.20%), confirm that the airport has begun to stabilize and regain financial efficiency.

In addition to analyzing financial indicators, passenger traffic trends are a key measure of the investment's effectiveness. To better understand the scale of passenger traffic growth at Gdańsk Lech Wałęsa Airport, it is useful to compare its performance with other major regional airports in Poland. Figure 2 presents passenger traffic volumes for the period 1999-2023 across six key airports: Warsaw Chopin, Kraków, Gdańsk, Katowice, Wrocław, and Poznań. Between 2010 and 2019, Gdańsk Airport recorded a substantial increase in passenger numbers—from 2.2 million to 5.4 million—exceeding its target capacity set during the investment planning phase.

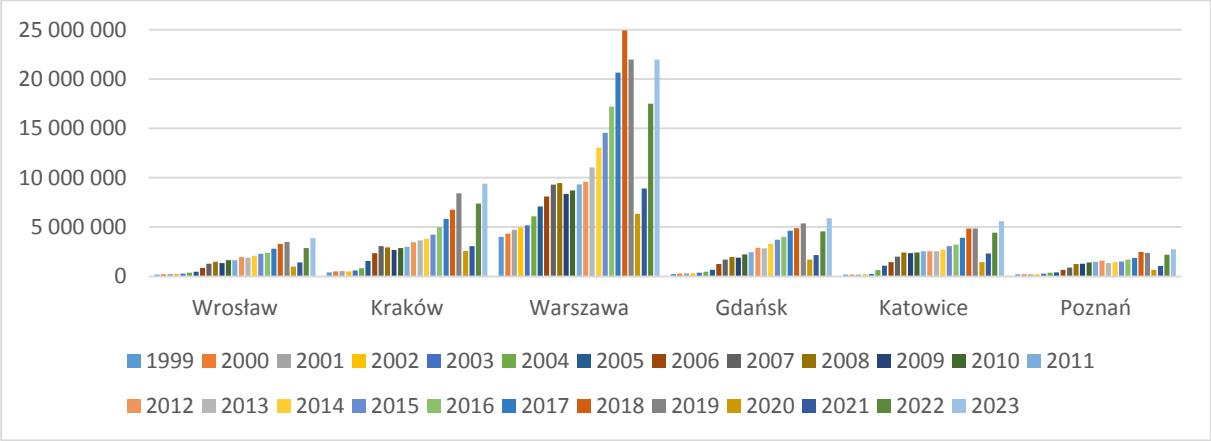

Figure 2. Passenger traffic at selected Polish airports in the period 1999-2023.

Source: authors' own elaboration based on official airport statistics by GUS, Bank Danych Lokalnych.

This upward trend is consistent with national patterns, but the scale of increase in Gdańsk outpaced several other regional hubs during the same period. The observed growth aligns closely with the completion of the infrastructure investment phase (2010-2015), which expanded the airport's operational capacity and improved service quality. As seen in Figure 2, only Kraków and Warsaw recorded higher absolute passenger volumes in 2023, but the relative growth rate in Gdańsk during the analyzed period remains among the most dynamic. These comparative data confirm that the infrastructure expansion not only enabled increased traffic handling capabilities but also met growing regional demand for air transport services. By 2024, the airport had served nearly 6.7 million passengers, reflecting continued post-pandemic recovery and demand growth (Table 5). According to projections by the airport authorities, Gdańsk Lech Wałęsa Airport is expected to handle up to 9.5 million passengers annually by 2035.

Table 5.
Operations data in 2010-2024 in Gdańsk Lech Walesa Airport

Year	Passenger service capacity	Annual runway capacity (operations/hour)	Cargo (metric tons)
2010	2 231 610	31 276 (3,6)	4 487
2011	2 463 222	34 364 (3,9)	4 944
2012	2 906 091	40 044 (4,6)	4 851
2013	2 844 308	35 908 (4,1)	4 943
2014	3 288 251	40 047 (4,6)	5 658
2015	3 706 180	40 261 (4,6)	5 162
2016	4 004 081	41 079 (4,7)	4 864
2017	4 611 714	43 422 (5,0)	5 549
2018	4 980 647	46 482 (5,3)	6 213
2019	5 376 120	48 882 (5,6)	6 887
2020 (pandemic year)	1 711 281	11 586 (1,3)	7 028
2021	2 155 470	29 298 (3,3)	9 171
2022	4 576 705	43 987 (5,0)	10 189
2023	5 907 280	49 502 (5,7)	11 483
2024	6 714 149	56 839 (6,5)	11 681

Note: "Operations/hour" indicates the average number of aircraft operations per hour calculated over the operating hours of the airport.

Source: own elaboration based on data obtained from Gdańsk Lech Walesa Airport.

Between 2010 and 2024, the airport recorded a steady increase in passenger, operational, and cargo capacity, with the exception of a sharp decline in 2020 due to the COVID-19 pandemic. The number of passengers served rose from 2.2 million in 2010 to over 6.7 million in 2024 an almost threefold increase. Simultaneously, annual runway capacity increased from 31,000 to nearly 57,000 operations, while cargo volumes grew from 4,500 to more than 11,600 metric tons. Data from 2022 to 2024 reflect a strong recovery and continued growth potential for the airport. The condition of the airport infrastructure on the side of airside after modernization, as declared by the airport, allows for the handling of 30 air operations within an hour. So far, the largest number of air operations took place in 2024. At that time, 56 839 air operations were handled. The average number of operations per hour is thus close

to 6.5 (assuming that the number of hours per year is around 8760). This is an average result, which is not adequate to the maximum capacity of handling air operations at the airport in Gdańsk. Increased air traffic is observed in the morning hours, while at night it is kept to a minimum. For the above reasons, the detailed capacity analysis in this aspect cannot be determined on the basis of the data obtained.

6. Effects for the region

Key environmental issues and airport development challenges are increasingly analyzed through the lens of sustainable development, due to their impact on the quality of life of nearby residents, the spatial and economic dynamics of surrounding areas, and the condition of the environment (GAO, 2000). As confirmed by Rucińska and Ruciński (2017) as well as Koszarek-Cyra and Wojewnik-Filipkowska (2023), airport operations generate both benefits and costs, and the overall impact depends on how these effects are distributed.

Recent theoretical and practical approaches emphasize that airports have evolved into regional growth engines. According to Appold and Kasarda (2013), modern airports function as multifunctional "airport cities"—hubs of commerce, logistics, and urban expansion that attract investment and employment far beyond their terminals. In line with this model, Gdańsk Lech Wałęsa Airport has had a profound effect on its surroundings, particularly following major infrastructure investments implemented after 2010.

Positive impacts include:

- satisfying social and economic transportation needs,
- improved regional accessibility, especially after the launch of the Pomeranian Metropolitan Railway (2015),
- increased societal mobility and tourism development,
- attraction of low-cost carriers and expanded frequency of international connections,
- increased business and leisure air traffic,
- job creation – by 2023, nearly 7000 people were employed directly or indirectly in airport-related activities (Koszarek-Cyra, Wojewnik-Filipkowska, 2023). Projections indicate that this number may further increase due to ongoing expansion. International research confirms a strong correlation between proximity to an airport and local job density[2],

[2] Research conducted in the United States by Appold and Kasarda found that 3.1 million jobs (2.82 percent of employment in the US) were within 2.5 miles of the border fence of the 25 busiest passenger airports in 2009. More than 7.5 million jobs (6.78 percent of US employment) were within 5 miles of the same airports, while 19.0 million jobs (17.17 percent of the total) were within 10 miles (Appold, Kasarda, 2013, p. 1247).

- accelerated suburban expansion and land-use transformation – residential areas such as Banino, Kokoszki and Jasień experienced substantial growth, with population increases of 363%, 245% and 232% respectively between 2005 and 2022 (Koszarek-Cyra, Wojewnik-Filipkowska, 2023),
- increased land value – particularly in areas previously classified as agricultural, now being converted for residential or industrial purposes (Rucińska, Ruciński, 2017).

Such developments are consistent with broader theoretical frameworks on infrastructure-driven growth. Romer (1986) and Lucas (1988) demonstrated that increasing returns from infrastructure investments stimulate long-term economic expansion. Barro and Sala-i-Martin (2004) emphasized the role of regional capital accumulation and transport connectivity in reducing disparities. Similarly, Dolata (2015) and Ratajczak (2000) pointed to transport infrastructure as a key factor in sustainable spatial development.

However, rapid airport-driven development brings challenges:

- insufficient road and public transport infrastructure, leading to congestion during peak hours,
- reduction of biologically active areas due to urban sprawl,
- increased noise and air pollution related to air traffic,
- potential water contamination from de-icing and apron runoff,
- spatial planning conflicts – over 60% of local development plans (LDPs) in the airport's vicinity allocate land for residential use, while only 1.7% designate industrial functions, resulting in functional incompatibilities (Koszarek-Cyra, Wojewnik-Filipkowska, 2023).

To monitor and mitigate the environmental impact of its operations, Gdańsk Airport has implemented a noise monitoring and measurement system related to aviation activity, as well as periodic assessments of rainwater discharged into drainage ditches. These tests have not revealed any significant environmental risks. Nevertheless, even in the absence of clear harm, it is reasonable to assume that some environmental impact is inherent to airport operations. As Lidskog and Soneryd (2000) emphasize, compliance with environmental norms alone is not enough-major infrastructure projects must also be socially inclusive, addressing public concerns and ensuring meaningful engagement of affected communities.

Despite these challenges, cost-benefit analyses indicate that the advantages of airport operations generally outweigh their costs-provided effective mitigation measures are implemented. Pearce, Atkinson and Mourato (2006) stress that environmental externalities should be systematically accounted for in such assessments, and the European Commission (2014) highlights the importance of monetizing both environmental and social impacts when appraising large infrastructure investments.

Ultimately, the case of Gdańsk Lech Wałęsa Airport reflects a broader trend observed across Europe and globally: airports play a growing role in regional development, but this growth must be accompanied by thoughtful spatial planning, environmental stewardship, and open dialogue with the public.

7. Conclusion

The ex-post analysis confirms that the infrastructure investment at Gdańsk Lech Wałęsa Airport was successful and met its strategic objectives. The target capacity of handling over 5 million passengers annually was reached in 2019, just a few years after the commissioning of the new T2 terminal. Although the COVID-19 pandemic temporarily disrupted air traffic, the airport has since returned to a growth trajectory, supported by positive financial, operational, and socio-economic indicators.

The investment not only enhanced the airport's technical performance - achieving ILS Category IIIb capability and increasing hourly runway capacity - but also generated significant regional impacts. These include job creation, increased land and property values, suburban expansion, and the stimulation of commercial activity, including the ongoing Airport City development. The stable financial condition of the airport enables the continuation of new investment projects, such as the construction of the western pier.

Importantly, the investment fulfilled expectations not only of the airport operator but also of public stakeholders. It improved the mobility of residents in the Tri-City and surrounding areas and aligned with the long-term development strategy of the Pomeranian Voivodeship. The project also contributed to the liberalization and competitiveness of the Polish aviation sector, increasing the range and frequency of international connections for both business and leisure travellers.

From a public policy perspective, the project exemplifies the effective use of EU and national funds to support long-term regional growth. It demonstrates how transport infrastructure can simultaneously fulfill economic and social utility goals. Moreover, the evaluation provides practical insights into the management of large-scale infrastructure projects and the effective allocation of public resources. In the context of Poland's relatively young and rapidly changing aviation sector, such experience supports institutional learning and strategic planning for future investments.

Moreover, the findings confirm the catalytic role of airport infrastructure in regional economic transformation, as anticipated in endogenous growth theories (e.g., Romer, Lucas). At the same time, they underscore the importance of integrated spatial and environmental governance in mitigating externalities from such projects. Methodologically, the study demonstrates the relevance of ex-post evaluation in assessing large-scale infrastructure outcomes, which may be useful for similar regional case studies.

Nonetheless, the study acknowledges limitations related to the observation period, which ended with the onset of the COVID-19 pandemic. Air operations were nearly frozen during some periods, and some regional investments were delayed. These disruptions should be taken into account in further impact assessments.

Future research should explore the long-term effects of subsequent development stages, including aspects of social equity, climate resilience, and regional integration within the trans-European transport network.

References

1. Appold, S.J., Kasarda, J.D. (2013). The Airport City Phenomenon: Evidence from Large US Airports. *Urban Studies, 50(6),* 1239-1259. DOI: https://doi.org/10.1177/0042098012464401.
2. Barro, R.J., Sala-i-Martin, X.I. (2004). *Economic Growth. Second edition*. Cambridge, Massachusetts: The MIT Press. ISBN 978-0262025539.
3. Dolata, M. (2015). Znaczenie infrastruktury w koncepcji trwałego i zrównoważonego rozwoju obszarów wiejskich (Importance of Sustainable Infrastructure In Concept of Sustainable Development of Rural Areas). *Zeszyty Naukowe Uniwersytetu Szczecińskiego. Studia i Prace Wydziału Nauk Ekonomicznych i Zarządzania*, *40, T.2. Problemy współczesnej ekonomii,* pp. 45-55, DOI: 10.18276/sip.2015.40/2-04
4. Dunford, M. (2009). Regional Development Models. In: K. Rob, N. Thrift (eds.), *International Encyclopedia of Human Geography*. Elsevier, doi: https://doi.org/10.1016/B978-008044910-4.00868-3
5. Forsyth, P. (2018). Pre-financing airport investments, efficiency and distribution: Do airlines really lose? *Journal of Air Transport Management*, *Vol. 67*, pp. 259-267, doi: https://doi.org/10.1016/j.jairtraman.2017.03.008.
6. GAO (Government Accounting Office) (2000). *Aviation and the environment: results from a survey of the nation's 50 busiest commercial service airports*. RCED-00-222, GAO. Washington, DC. https://www.gao.gov/assets/rced-00-222.pdf, 20.10.2021.
7. Guide to Cost-Benefit Analysis of Investment Projects. Economic appraisal tool for Cohesion Policy 2014-2020. European Commission, Directorate – General for Regional and Urban policy, December 2014. https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf, 10.09.2021.
8. Kokot, S. (2021). Socio-economic factors as a criterion for the classification of housing markets in selected cities in Poland. *Real Estate Management and Valuation*, *28(3),* pp. 77-90. doi: https://doi.org/10.1515/remav-2020-0025.
9. Koszarek-Cyra, A., Wojewnik-Filipkowska, A. (2023). Managing the airport-proximate areas. *Scientific Papers of Silesian University of Technology, Organization and Management Series, no. 181,* pp. 259-277. doi: http://dx.doi.org/10.29119/1641-3466.2023.181.18.

10. Lidskog, R., Soneryd, L. (2000). Transport infrastructure investment and environmental impact assessment in Sweden: public involvement or exclusion? *Environment and Planning A, Vol. 32, No. 8,* pp. 1465-1479, doi: https://doi.org/10.1068/a32228.
11. Lucas, R.E. Jr. (1988). On the mechanics of economic development. *Journal of Monetary Economics, 22*, pp. 3-42.
12. Macioszek, E. (2021). Functioning of selected airports in Poland. *Scientific Journal of Silesian University of Technology. Series Transport*, *112*, pp. 135-144. doi: https://doi.org/10.20858/sjsutst.2021.112.7.11.
13. Ogburn, W.F. (1946). Inventions of Local Transportation and the Patterns of Cities. *Social Forces*, *Vol. 24, Iss. 4,* pp. 373-379, doi: https://doi.org/10.2307/2572206.
14. Parysek, J. (2001). *Podstawy gospodarki lokalnej (Fundamentals of the local economy)*, Poznań: Wydawnictwo Naukowe Uniwersytetu w Poznaniu, ISBN 83-232-0796-8.
15. Pearce, D.W., Atkinson, G., Mourato, S. (2006). *Cost-Benefit Analysis and the Environment. Recent Developments.* Paris: OECD Publishing, doi: https://doi.org/10.1787/9789264010055-en.
16. Quinet, E. (2007). Cost–Benefit Analysis of Transport Projects in France. In: Florio Massimo (ed.), *Cost–Benefit Analysis and Incentives in Evaluation*, *chapter 7*. Edward Elgar Publishing. ISBN 978 1 84720 238 3.
17. Ratajczak, M. (2000). Infrastruktura a wzrost i rozwój gospodarczy (Infrastructure and economic growth and development). *Ruch Prawniczy, Ekonomiczny i Socjologiczny*, *LXII(4),* pp. 83-102.
18. Romer, P.M. (1986). Increasing returns and long-run growth. *Journal of Political Economy, 94*, pp. 1002-1037.
19. Rosenstein-Rodan, P.N. (1957). Notes on the theory of the "big push". *Economic Development Program, Italy Project C/57-25.* Center for International Studies, Massachusetts Institute of Technology Cambridge. MIT Libraries https://dspace.mit.edu/handle/1721.1/82984 (14.09.2024).
20. Rosenstein-Rodan, P.N. (1976). The Theory of the „Big Push". In: G.M. Meier Gerald, J.E. Rauch (eds.), *Leading Issues in Economic Development.* New York: Oxford University Press, ISBN 978-0195179606.
21. Rucińska, D., Ruciński, A. (2017). Współzależności rozwoju portów lotniczych i struktur zagospodarowania przestrzeni z uwzględnieniem stref okołolotniskowych (Interdependence of airport development and space management structures with consideration the airport-related areas). *Prace Komisji Geografii Komunikacji PTG, 20(2),* pp. 57-68. https://doi.org/10.4467/2543859XPKG.17.011.7393.
22. Schulze, J.H., Jensch, G. (ed.) (1959). *Zum Problem der Weltstadt*. Festschrift zum 32. Deutschen Geographentag in Berlin 20-24. Berlin: Verlag Walter de Gruyter.
23. Solow, R.M. (1956). A contribution to the theory of economic growth. *The Quarterly Journal of Economics, 70 (February),* pp. 65-94. doi: https://doi.org/10.2307/1884513.

24. *Studies on the long-term adjustment of the International Gdańsk Lech Walesa Airport, a TEN-T node in the North Poland, for air transport needs*; 2008-pl-92005-s_.pdf, 10.09.2024.
25. Urfer, B., Weinert, R. (2011). Managing Airport Infrastructure. In: A. Wittmer, T. Bieger, R. Muller (eds.), *Aviation systems*. Berlin/Heidelberg: Springer, doi: https://doi.org/10.1007/978-3-642-20080-9.
26. Wojewnik-Filipkowska, A. (2008). *Project Finance w inwestycjach infrastrukturalnych* (Project Finance in infrastructure investment). Warszawa: CeDeWu. ISBN 978-83-7556-060-2.
27. World Bank (1994). *World Development Report 1994: Infrastructure for Development*. New York: Oxford University Press. World Bank. Available at: https://openknowledge.worldbank.org/handle/10986/5977 License: CC BY 3.0 IGO.

Footnotes

[1] The financing of such projects may vary, they may be funds obtained from prepayments. They are very often used by airports to fund major investments, such as runways and terminals. It involves the airport charging airlines higher prices as soon as, and sometimes before, the project's construction commences, often well before it becomes operational (Forsyth, 2018, 259). This form of financing is available for the higher rank airports. Those of lesser rank use traditional forms of financing and combine equity capital with borrowed capital. Public funds are also used, and in the case of member states - the EU funds.

[2] Research conducted in the United States by Appold and Kasarda found that 3.1 million jobs (2.82 percent of employment in the US) were within 2.5 miles of the border fence of the 25 busiest passenger airports in 2009. More than 7.5 million jobs (6.78 percent of US employment) were within 5 miles of the same airports, while 19.0 million jobs (17.17 percent of the total) were within 10 miles (Appold, Kasarda, 2013, p. 1247).

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MANAGING FLIGHTS DURING FOG EVENTS ON THE EXAMPLE OF KRAKÓW-BALICE AIRPORT

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Purpose: To quantify the impact of fog on flight diversions at Kraków Airport (EPKK) and to analyze the implications of this operational vulnerability, specifically in relation to the airport's Category I Instrument Landing System (ILS).
Methodology: This study employed a retrospective, quantitative research design to empirically investigate the influence of fog on aircraft diversions at EPKK. The study is a flight operations data (Eurocontrol PRISME) and meteorological records (METAR) analysis using a four-month annual sample allowing for a longitudinal examination of patterns and correlations over an extensive eight-year period (2015-2023). All data acquisition, processing were conducted using custom scripts developed in the Python programming language.
Findings: Fog is the primary driver of disruptions, causing 63.6% of all flight diversions in the sample. These events are highly seasonal, peaking in December, and are a direct consequence of visibility frequently dropping below the airport's CAT I operational minima. This forces a heavy reliance on Katowice Airport (EPKT) as the primary alternate destination.
Research limitations: The primary limitation is the use of sampled monthly data, which may not capture the full annual impact.
Originality: This paper provides novel, quantitative evidence linking specific fog characteristics to operational disruption rates at a major Polish airport. It offers significant value to airport managers, airline strategists, and transport policymakers by grounding critical investment decisions in robust, empirical data.
Keywords: flight diversions, low visibility procedures, fog.
Category of the paper: General Review.

1. Introduction

With air transport operations becoming the most viable form of passenger transport, it took the regional and global markets by storm becoming the threads of the connectivity network. It facilitates and indicates economic growth of the region, enables touristic traffic and travel for business enterprise. Airports, as the basic nodes in the network, require high reliability and operational upkeep to meet increasing demand for air travel. However, performance of these hubs might be undermined dramatically by various factors, among which, include adverse weather conditions that pose a persistent and complex challenge. Fog, in particular, by directly impacting pilots' visual references is one of phenomenon requiring airports to implement specific operational procedures, very often reducing capacity. The consequences of severe fog conditions are far-reaching and can lead to further delays, cancelled flights and diversions to other airports. All those send ripple waves through operator networks, affecting schedules, crew rosters, aircraft schedules and making the passenger experience much less pleasant. Therefore, understanding and managing adverse fog events is critical to airport and aircraft operators.

John Paul II International Airport Kraków-Balice (EPKK/KRK), regional hub for Lesser Poland Region in southern part of the country is notably susceptible to fog. The geographical location, particularly close proximity to the Vistula River and surrounding terrain can favor the formation of radiation fog, especially during autumn and winter months. This occurrence frequently translates into operational challenges for Kraków Airport, with media coverage and preliminary observations attributing large number of flight diversions to neighboring airports to low visibility conditions at EPKK. Not only this incurs direct financial costs for airlines but also affects nearby airports resources and disrupts the travel plans of thousands of passengers annually.

2. Literature Review

In Poland, the fog that forms are usually radiation fog, which happens when there are clear skies, light winds, and high humidity, mostly at night and in the early morning. The southern part of the country, around its largest city, Kraków, is known for having fog form frequently. This is because of its specific geography, namely its location in the Upper Vistula River basin and its closeness to hilly terrain (Łupikasza, Niedźwiedź, 2016; Skrzyńska, 2019).

Further studies by Łupikasza and Niedźwiedź (2016) confirm that Kraków has a high number of foggy days each year, with averages between 53 and 67 days. The fog is most common between September and January, with October being the month with the most fog. Recent climatological studies by Zawadzka-Manko and Markowicz (2025) show that fog in inland southern Poland usually lasts from 3.7 to 6.1 hours, and visibility often drops below 500 meters. Even though some areas in Poland have seen fewer foggy days because of climate change, Kraków hasn't had a big decrease, probably because the local basin microclimate, which traps cold air, is still there (Skrzyńska, 2019).

2.1. Airport Operations

Fog is a major problem for airport operations because it reduces visibility, which is essential for landing, taking off, and moving planes on the ground (Figure 1).

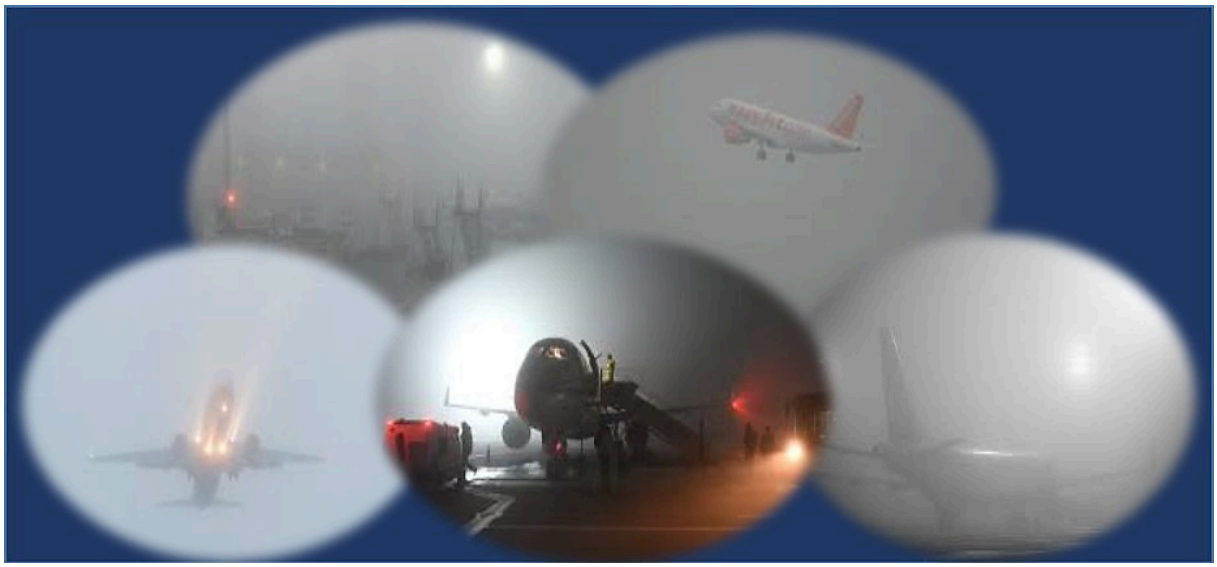

Figure 1. Fog as a major problem for airport in Kraków.

Source: own elaboration based on random google search images results.

When the Runway Visual Range (RVR) is lower, pilots have to switch to Instrument Flight Rules (IFR) and use Instrument Landing Systems (ILS). The disruption to operations caused by fog is well-documented all over Europe. Research by Pilguj et al. (2020) shows that events with limited visibility happen most often in the autumn and winter, which matches the seasonal fog patterns in Poland. Low visibility not only affects planes that are arriving and departing but also puts extra pressure on air traffic control and ground crews. Case studies from Polish airports show that thick fog often leads to go-arounds and holding patterns, which adds extra costs for fuel and time (Skomorowski, Piotrowski, 2018).

John Paul II International Airport Kraków-Balice (EPKK) is particularly at risk for fog-related problems because it's in a valley and has a lower level of technology. The airport currently uses a Category I Instrument Landing System (ILS), which only lets planes land if the RVR is 550 meters or more. This limit is often not met during the autumn and winter, which causes frequent diversions to other airports.

A study by Kwasiborska et al. (2023) that looked at the 2019 operations at EPKK found that the airport had 160.5 hours where operations were stopped or limited because of low visibility. In comparison, Warsaw Chopin Airport (EPWA), which has a Category III ILS, had zero hours of these kinds of disruptions in the same year. Katowice–Pyrzowice Airport (EPKT), with a Category II ILS, had far fewer hours of disruption (60.5 hours). This shows how important better navigation systems are for dealing with the impact of fog. These disruptions have both direct and indirect effects. Airlines have to pay more for fuel and crew time, and passengers have to deal with delays, cancellations, and missed connections. The operational problems also affect nearby airports, which have to take in diverted flights, impacting the entire air transport network. Upgrading EPKK to a higher-category ILS would greatly improve its ability to handle these situations. Kwasiborska et al. (2023) estimate that putting in a Category II ILS could cut down on weather-related operational downtime by as much as 50%, and a Category IIIa system could reduce it by almost 65%.

3. Research Methodology

This study used a quantitative, archival research method to look into how fog affects aircraft diversions at John Paul II International Airport Kraków-Balice (EPKK). The main approach was to collect, process, and analyze historical weather and flight data from an eight-year period, from March 2015 to March 2023.

There were two main sources of data. Weather records, specifically the Terminal Aerodrome Forecasts (METAR) for EPKK, were taken from the Iowa Environmental Mesonet (IEM) Automated Surface Observing System (ASOS) data archive. These reports were then put into a structured format for analysis. At the same time, aircraft operational data, which included details on flight arrivals and diversions, was gathered from the Eurocontrol PRISME (Pan-European Repository of Information Supporting the Management of EATM) database. A key limitation was that the PRISME data was only available for certain months—March, June, September, and December—for each year in the study. All the initial data work, like getting, organizing, filtering, and combining the datasets, was done using special software scripts in Python.

A core part of the analysis was clearly defining the key variables. A "fog event" that could be linked to diversions at EPKK was defined by METAR reports showing the "FG" (fog) weather code along with a reported horizontal visibility of 550 meters or less. An "aircraft diversion" was counted from the Eurocontrol data whenever a flight that was planned to land at EPKK ended up landing somewhere else. To connect these two things, a "fog-related diversion" was defined as any diversion where the plane landed at another airport within one hour before or after a recorded fog event at EPKK. This time link, based on timestamps, was key to connecting specific fog conditions with the diversions.

The data analysis was done in two main parts. First, a descriptive analysis was done to understand the characteristics of both fog events and diversions. This included figuring out the frequency and timing (yearly, seasonally, and daily) of major fog episodes. The main features of these episodes, like how long they lasted and the visibility levels, were also measured. At the same time, the total number of diversions was studied to find trends and patterns, including which alternate airports were used most often. In the second part, an inferential analysis was carried out to test the relationship between fog and diversions. The main tool used was the Pearson correlation coefficient (R). This statistical test measured how strong and in what direction the linear relationship was between the total hours of significant fog each month and the total number of fog-related diversions in that same month. A p-value was also calculated to see if this correlation was statistically significant.

Ethical concerns were handled by making sure all the data, both from Eurocontrol and the public weather data, was anonymous. No personal information about crew, passengers, or air traffic controllers was used or needed. The data was used according to the relevant agreements and only for the purpose of this research, which was to analyze how fog impacts aircraft diversions.

Finally, when looking at the results of this study, it's important to remember some limitations of the methodology. Because the Eurocontrol data was only from specific months, the conclusions are mostly about what happens during those times and might not apply to the whole year. Defining a fog event based on 1-hour METAR reports might not perfectly capture when fog started or ended. Also, the ±1-hour window for classifying a diversion as fog-related shows a strong connection in time, but it doesn't prove cause and effect, as other things happening at the same time could have played a role, or some fog-related diversions might have happened outside this window. The study also focused mainly on fog, and other reasons for diversions (like aircraft or crew certifications, airline rules, or other weather) were not included because of the study's scope and the data available. While the data sources are generally trustworthy, there is always a chance of small errors in large datasets.

4. Research Results

The analysis of flight operations data for John Paul II International Airport Kraków-Balice (EPKK) over an eight-year period from March 2015 to March 2023, sampled from the months of March, June, September, and December, found a total of 206 flight diversions. A careful and detailed analytical process was used on each of these diversions to see how they were related to the weather conditions. This meant classifying any diversion as "fog-related". The most important and clear finding of this research was that 131 of the 206 diversions, which is a significant majority of 63.6%, were directly linked to heavy fog conditions. This first result is powerful, showing that widespread fog is the single biggest and most important factor causing flight diversions and operational shutdowns at EPKK in the studied data. It confirms that what people have been saying for a long time is actually a measurable and major operational problem.

The number of these diversions, especially the ones caused by fog, changes a lot from year to year. This points to the changing nature of weather patterns but also shows the airport's ongoing vulnerability. This is shown in detail in Table 1 and Figure 2. For example, the year 2020 stood out with the highest number of problems, with 58 total diversions, and a massive 54 of them (93.1%) were because of fog. Even though air travel was much lower globally during this time because of the COVID-19 pandemic, this finding strangely highlights how fundamental the impact of weather is. With fewer flights, the problems caused by bad weather became even more obvious and important, showing a basic weakness that is there no matter how much traffic there is. On the other hand, years like 2017 and 2018 had far fewer incidents, which suggests that during those times, the weather conditions were not as favorable for the formation of long-lasting, low-visibility fog in the area. This variation shows that while the risk isn't constant, in any year with bad weather patterns, fog quickly becomes the main cause of disruption.

Table 1.
Annual Diversion Summary

Year	Total Diversions	Fog-Related Diversions	Percentage of Fog Diversions (%)
2015	46	34	73.9
2016	29	24	82.8
2017	9	0	0
2018	7	2	28.6
2019	9	4	44.4
2020	58	54	93.1
2021	19	7	36.0
2022	25	6	24
2023	3	0	0

Note. 2023 data is partial (March only).

Source. Own elaboration based on Eurocontrol PRISME database.

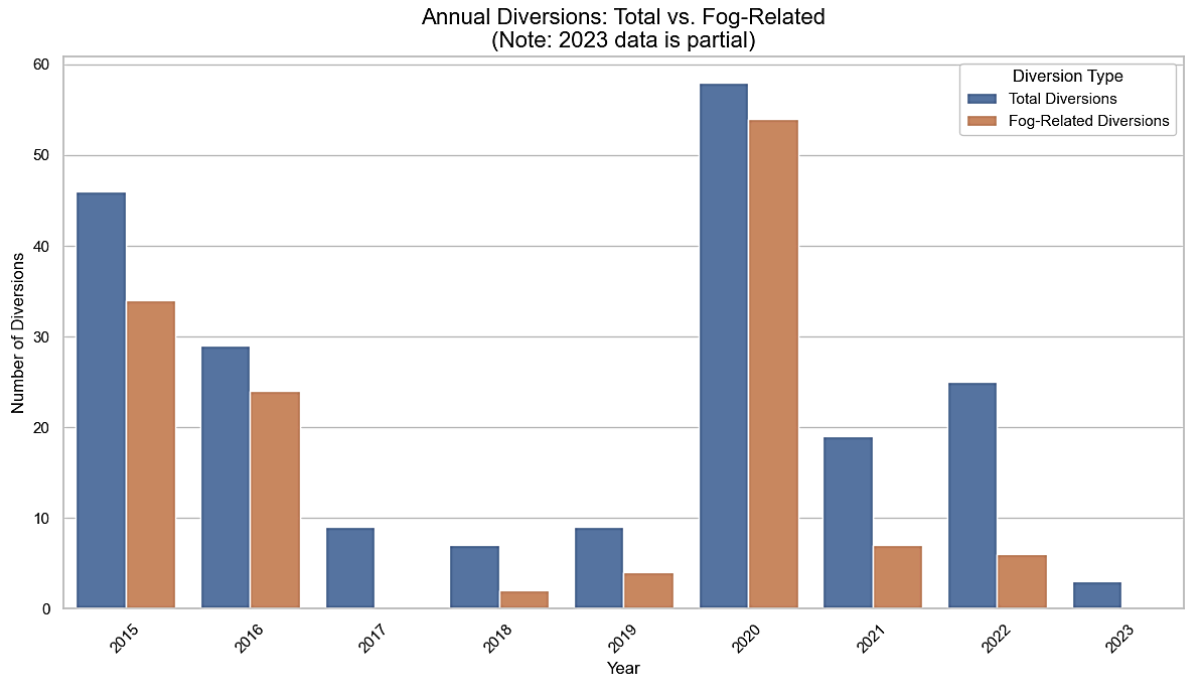

Figure 2. Annual Diversions: Total vs. Fog-Related.

Source: Own elaboration.

A very strong and important seasonal trend is also clear in the data, identifying a specific time of year when the operational risk for the airport is highest. The monthly breakdown, shown in Table 2, shows that December is affected much more than other months and can be seen as the center of weather-related operational problems for EPKK. During the study period, the sampled December months alone had an incredible 138 total diversions, with 117 of those (an amazing 84.8%) being classified as fog-related. This high number of incidents in a single month is a big contrast to the quiet operations during the summer; the sampled June months, for instance, had only one fog-related diversion over the entire eight-year period. The detailed time-series analysis in Figure 3 visually confirms this sharp seasonal difference, showing clear, sharp, and repeated spikes in both the total hours of fog and the number of aircraft diversions almost only during the late autumn and winter months. This gives airport management a clear and predictable calendar of its highest operational risk.

Table 2.
Summary by Month

Month	Total Fog Hours	Total Diversions	Fog-Related Diversions	Percentage of Fog Diversions (%)
March	879	14	5	35.7
June	155	31	1	3.2
September	577	22	8	36.4
December	2167	138	117	84.8

Note. 2023 data is partial (March only).

Source: Own elaboration based on Eurocontrol PRISME database.

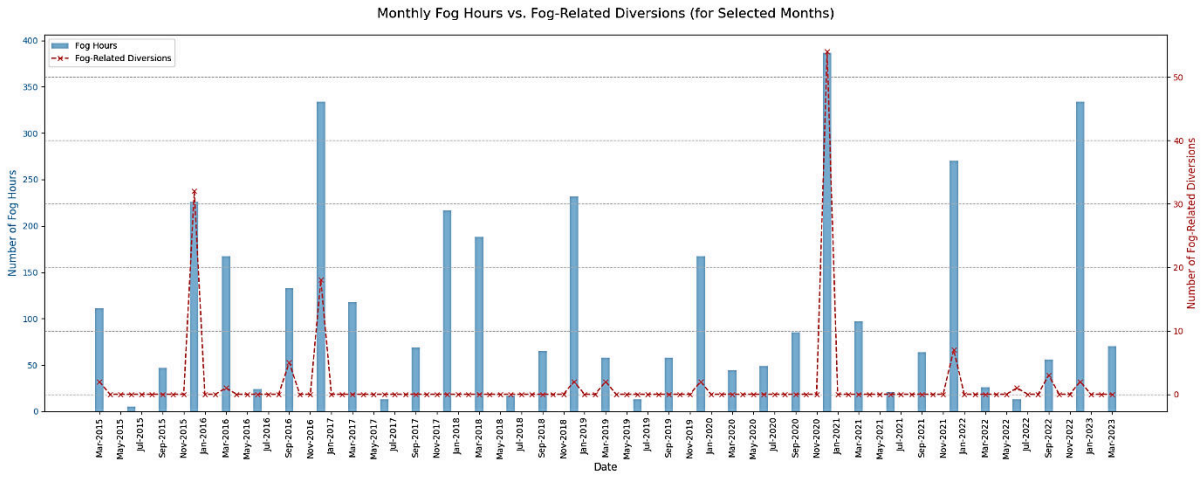

Figure 3. Monthly Fog Hours vs. Fog-Related Diversions.

Source: Own elaboration.

The specific timing and nature of these fog events are very important to fully understand how they disrupt airport management, airline schedules, and network stability. A detailed daily analysis confirms that fog at EPKK is mostly a nighttime and early-morning event, a pattern typical of the radiation fog common in the area. Figure 4 clearly shows that the most fog events happen between 02:00 and 07:00 UTC. This timing is especially bad from an operational standpoint because this window directly conflicts with important overnight cargo flights, the arrival of early-morning passenger flights that connect to other hubs, and the first wave of morning departures that set the pace for the airport's schedule for the whole day.

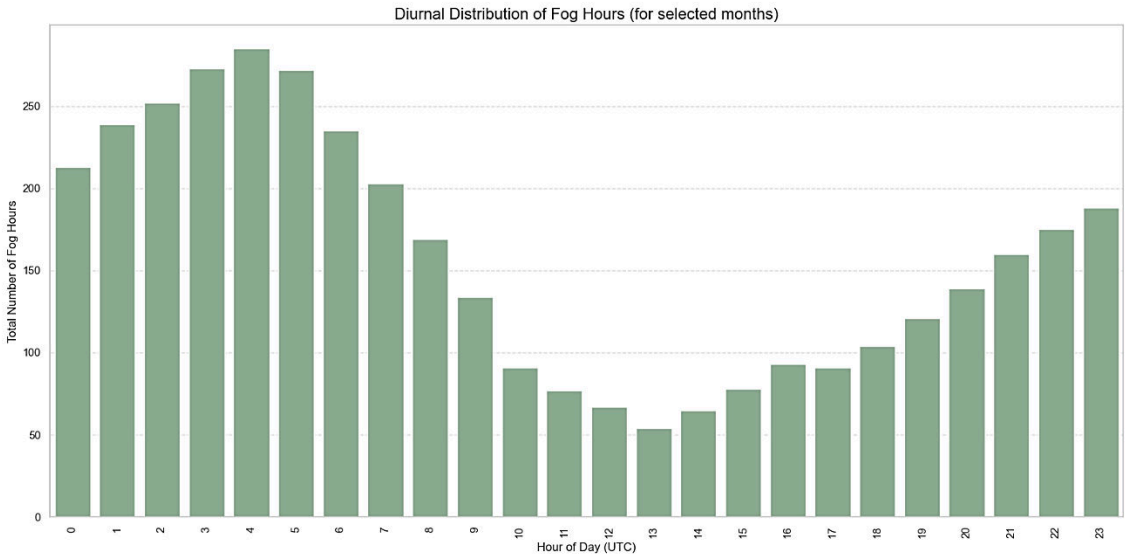

Figure 4. Diurnal Distribution of Fog Hours.

Source: Own elaboration.

The detailed heatmap in Figure 5 and Figure 6 adds to this understanding, showing that during the critical month of December, a thick blanket of high-probability fog often starts in the late evening and lasts through the entire morning, often not clearing until after 10:00 UTC. This creates a long and difficult period of deep operational uncertainty.

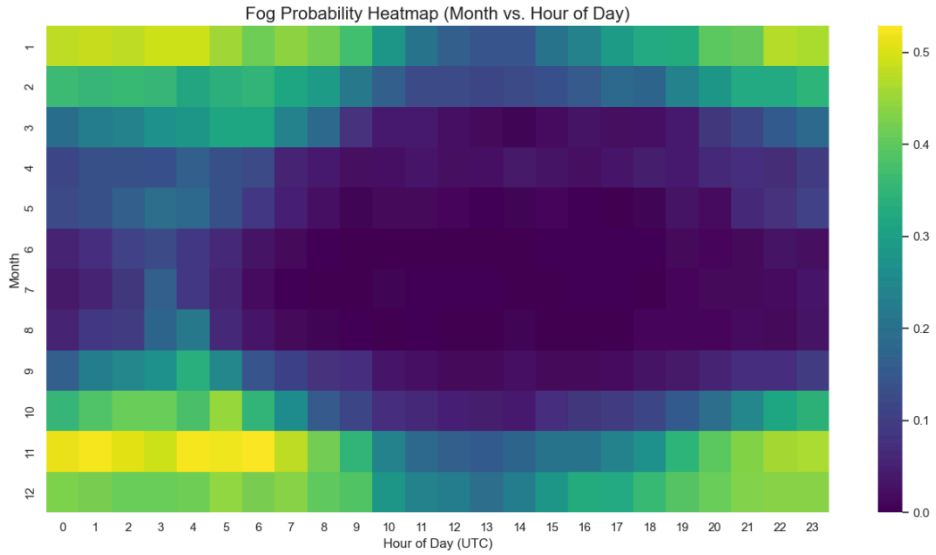

Figure 5. Fog Probability Heatmap by Month and Hour.

Source: Own elaboration.

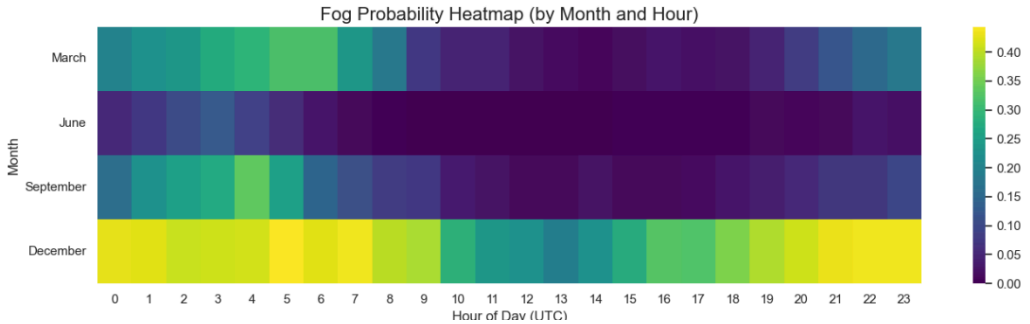

Figure 6. Fog Probability Heatmap by Month and Hour for selected months.

Source: Own elaboration.

The length of these events varies, with the median duration of a continuous fog episode being a significant 3.0 hours. However, the average of 6.2 hours is higher because of a few very disruptive long-lasting events, as shown in the distribution in Figure 7. This includes four separate episodes that lasted for over 48 hours, effectively shutting down normal operations for several days in a row. In the end, from a direct operational point of view, the recorded visibility during these events is the most important limiting factor.

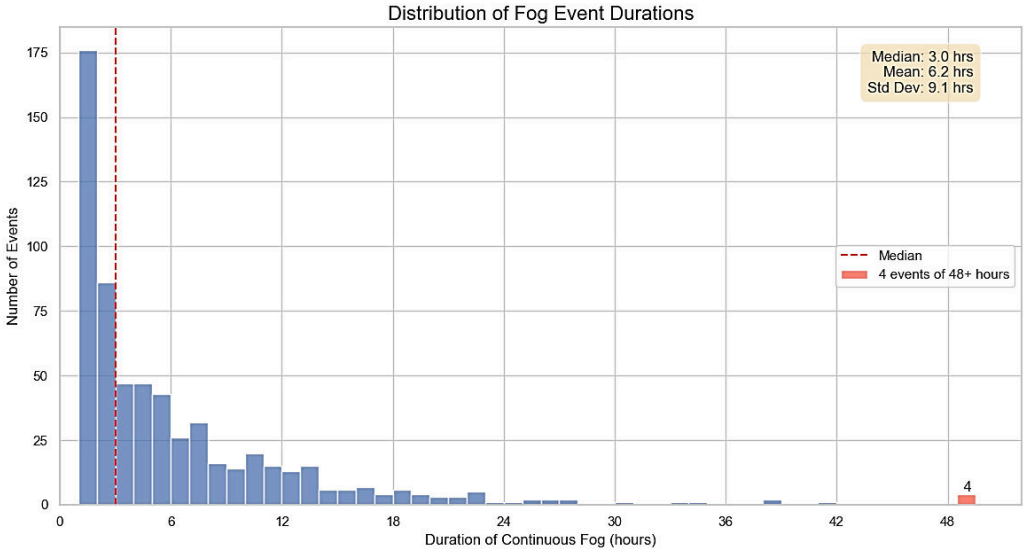

Figure 7. Histogram of Fog Event Durations.

Source: Own elaboration.

The analysis of visibility conditions shows that the airport's capacity is not just strained but often completely stopped. The median visibility during these fog episodes was measured at about 300 meters, a value shown in Figure 8. This is not just below, but critically below, the 550-meter Runway Visual Range (RVR) minimum required for the airport's Category I (CAT I) Instrument Landing System (ILS). This single piece of data provides the final explanation for the high rate of diversions, as these conditions make landings physically and legally impossible for most aircraft and flight crews.

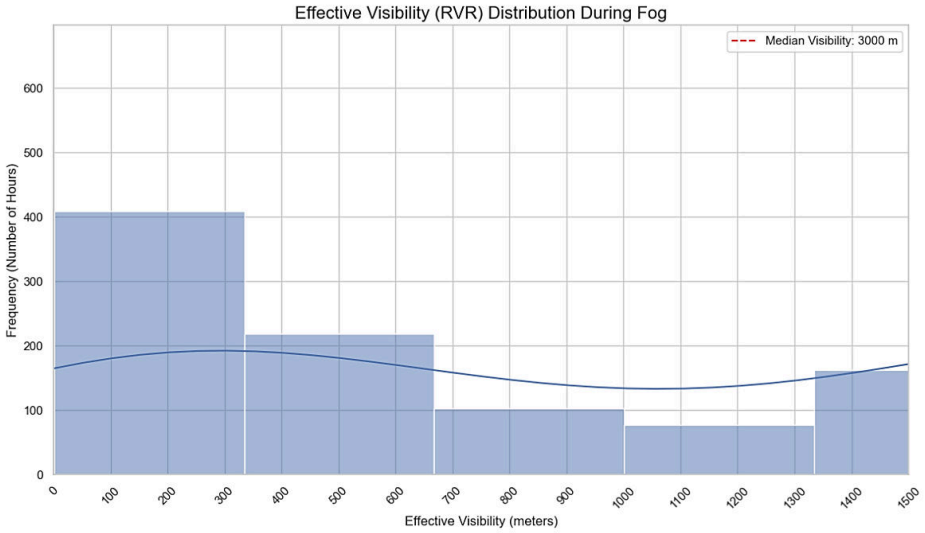

Figure 8. Histogram of Effective Visibility (RVR) Distribution.

Source: Own elaboration.

To confirm these observations, a formal statistical analysis was performed, which showed a significant and strong positive correlation between how long the fog lasted and the number of aircraft diversions. A Pearson correlation analysis looking at the relationship between the total number of fog hours per month and the number of fog-related diversions gave a correlation

coefficient (R) of 0.65 with a p-value (p) of less than 0.001. This is shown visually in the scatterplot in Figure 9. This result provides clear quantitative evidence that as fog conditions become more common and last longer, the number of flight diversions goes up in a predictable and moderately strong linear way, making the amount of fog a reliable predictor of operational problems.

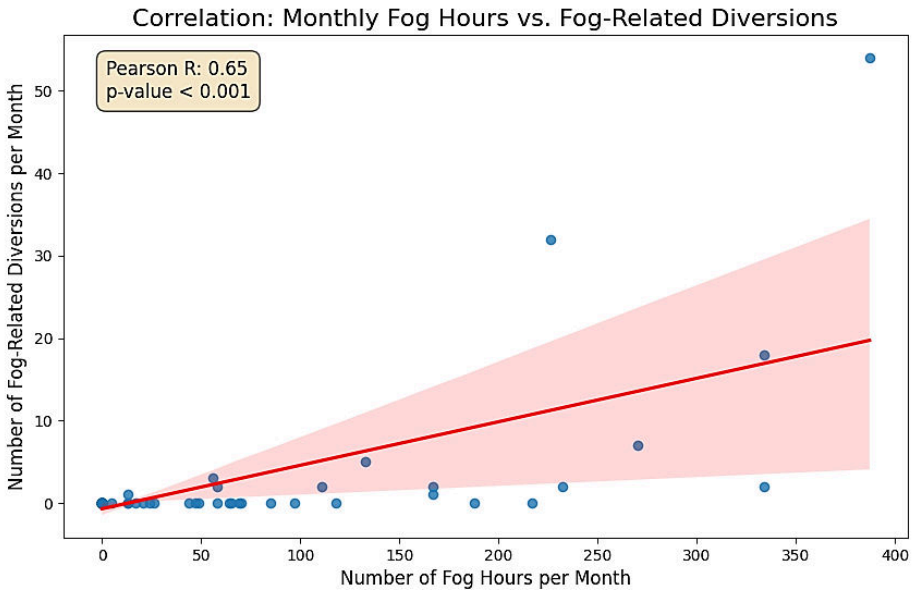

Figure 9. Scatterplot of Monthly Fog Hours vs. Fog-Related Diversions.

Source: Own elaboration.

When these diversions can't be avoided, the data shows that flights are systematically sent to one main alternate airport, which suggests a standard but very concentrated response from airlines. The data in Table 3 and the chart in Figure 10 show that the nearby Katowice Airport (EPKT) took in a huge 109 of the 131 fog-related diversions, which is 83.2% of the total. Warsaw Chopin Airport (EPWA) was the second most used diversion airport, taking 6 flights (6.8%). Other airports like Ostrava Leos Janacek Airport (LKMT) and Rzeszow-Jasionka Airport (EPRZ) each received 4 diversions.

Table 3.
Top 10 Fog-Related Diversion Airports

Alternate Airport	Number of Fog-Related Diversions
EPKT	109
EPWA	6
EPRZ	4
LKMT	4
EDDM	2
EPWR	2

Note. 2023 data is partial (March only).

Source. Own elaboration based on Eurocontrol PRISME database.

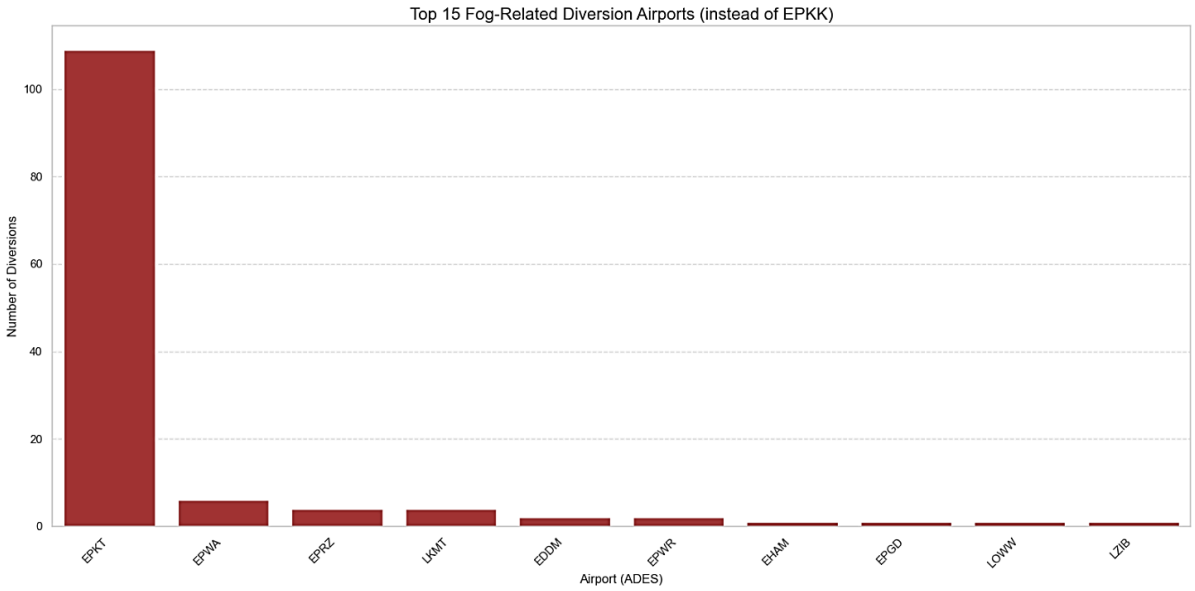

Figure 10. Top 10 Fog-Related Diversion Airports.

Source: Own elaboration.

The rest of the flights were sent to a wider variety of airports, each handling a smaller number, which shows a reliance on airports that are close by. This striking and heavy reliance on EPKT shows its absolutely critical role in the regional aviation network, acting as an essential backup for EPKK during bad weather and showing a deeply established, though potentially risky, network dependency.

5. Discussion

The results of this study provide strong quantitative evidence that fog is a major and frequent cause of significant operational problems at John Paul II International Airport Kraków-Balice. These findings are very important for the airport's management and strategy. They move the discussion from just talking about the weather to measuring the direct impact of this predictable weather event on airport operations, the stability of the regional network, and the business case for investing in infrastructure. The main point of this discussion is to see these numbers as a way to measure risk, responsibility, and the opportunity for improvement. The data changes the long-known "problem of fog" from something that is just accepted as an operational hassle into a measurable, predictable, and ultimately manageable strategic issue. At its core, this study measures a critical operational weakness that directly affects the airport's ability to provide service, its reputation, and its financial health.

The clear seasonal nature of fog, with the most occurrences in December and the least during summer months, matches the literature (Łupikasza, Niedźwiedź, 2016), which points to September to January as the main fog season for Kraków. This strong seasonal pattern

highlights the role of large-scale weather conditions that are common in autumn and winter. The daily pattern, with fog mostly happening at night and in the early morning (peaking around 03:00-04:00 UTC), supports the idea that the fog at EPKK is mainly radiational, as suggested by the literature for Poland (Łupikasza, Niedźwiedź, 2016; Skrzyńska, 2019), and is likely made worse by EPKK's location.

The finding that the median visibility during fog events is only 300 meters, which is much lower than the required 550-meter minimum for its Category I ILS, scientifically confirms the concerns that were brought up before by Kwasiborska et al. (2023). It shows without a doubt that a large number of the fog events that naturally happen at EPKK automatically force a stop to all incoming flights. Management should not see this situation as a random operational risk, but as a systemic weakness that is directly tied to the airport's current technology and infrastructure. The fact that this problem is very seasonal, with most of the disruptions happening in the autumn and winter, presents a repeating, predictable challenge to service reliability, passenger satisfaction, and internal planning. Therefore, the findings strongly suggest that a strategic upgrade to a Category II or, even better, a Category III Instrument Landing System—which are made specifically to allow landings in much lower visibility—is the most direct and effective way to fix this core operational weakness. Such an investment would be a major strategic change for the airport, moving it from a position of reacting to expensive disruptions to one of being proactive and operationally resilient, which would make it more competitive among regional airports.

The heavy reliance on the nearby Katowice Airport (EPKT) as the main alternate airport, taking in over 83% of all fog-related diversions from EPKK, shows a critical and deeply rooted network dependency. While on one hand, this shows that there is good informal cooperation in the region and gives airlines a way to cope, it also creates a major systemic risk for the wider network. Any operational problems at EPKT at the same time—like its own bad weather, runway maintenance, or being at full capacity—during a major fog event at EPKK could cause a chain reaction of failures throughout the regional air transport system. This would force airlines to divert to airports that are much farther away, more expensive, and logistically harder to manage. This "EPKT dependency" highlights a hidden weakness in the regional aviation infrastructure and shows why it is urgent for EPKK's management to think about the strength and backup options of the wider network as part of its long-term strategic planning. Furthermore, this situation puts EPKK at a clear competitive disadvantage. When airlines and logistics companies are making decisions about routes and where to set up bases, they do detailed risk assessments. An airport with a known, high chance of weather-related diversions and a reliance on a neighboring airport can be seen as less reliable and more expensive to fly from, which could discourage future investment and growth.

Each of the 131 fog-related diversions found in this study represents a chain of direct and indirect financial costs that affect the entire system. These include immediate costs for airlines, like a large increase in fuel used for the extra flight time, longer crew hours that can lead to

complicated scheduling problems and overtime pay, and landing and handling fees at the alternate airport. At the same time, there are major costs related to taking care of and compensating passengers, especially under rules like EU261, which require assistance and possibly financial payouts for long delays and cancellations. On top of these direct financial costs, the frequent and predictable disruptions cause damage that is harder to measure but just as bad, including a loss of passenger trust, a loss of customer loyalty, and significant harm to the reputations of both the airport and the airlines that fly there as reliable service providers. The predictable, seasonal nature of these disruptions means they are not unexpected but are a repeating problem that systematically hurts the efficiency and profitability of operations at EPKK and other airports in the region.

The detailed climatology of fog can also help with short-term operational planning. However, it is important to admit the limitations, mainly that the flight data was sampled from only four months per year. Because of this, the findings about annual diversion totals and the full extent of monthly correlations are based on these sampled periods. The definition of a "fog episode" for correlating with diversions, based on a METAR visibility of ≤550m and a fog indicator, might not capture all operationally important aspects of fog, and the time link shows a correlation, not a definite cause. Other factors that were not analyzed could also be part of the decision to divert. Lastly, the findings are specific to EPKK.

This study creates opportunities for more research, like expanding the diversion analysis to include data from the whole year, looking into the economic costs, or doing comparative studies with airports that have higher-category ILS systems.

6. Conclusions

This research gives a final, thorough, and data-supported assessment of the major operational and organizational impact of fog on Kraków Airport. It concludes with a high degree of confidence that fog is not just an occasional problem but is the single biggest, most predictable, and most impactful cause of flight diversions, being responsible for almost two-thirds of all such disruptions in the large dataset that was sampled. The study shows that this systemic weakness is fundamentally tied to the airport's current Category I Instrument Landing System. This system, while good enough for clear weather, is not technologically advanced enough to handle the low-visibility events that frequently and predictably cover the airport during the important autumn and winter seasons. The research measures the operational breaking point, showing that the median visibility during these events drops to levels that make landings impossible for a CAT I-equipped airport. The findings also highlight a major strategic dependency, with the vast majority of diverted flights being sent to the nearby Katowice Airport. This practice, while it works, creates a potential single point of failure in the regional aviation network and highlights a competitive disadvantage for EPKK.

From an organizational and management point of view, this research changes the way we talk about fog. It is shown not as an uncontrollable weather problem, but as a measurable business risk with significant, repeating financial and reputational costs. The constant cycle of diversions, delays, and passenger problems is a chronic operational issue that hurts efficiency, reduces profitability, and damages the airport's brand as a reliable international gateway. Therefore, this study provides the necessary quantitative basis and a clear reason for airport leadership, airline partners, and regional stakeholders to have a serious, data-based discussion about strategic infrastructure development. The main recommendation from this analysis is the critical need to pursue an upgrade of the airport's landing systems. Investing in a Category II or III ILS should not be seen as just a technical project or an optional expense. Instead, it must be seen as a strategic and essential investment in the airport's future. The return on this investment would be measured in much-improved operational resilience, a huge reduction in costly disruptions, better service reliability and passenger satisfaction, and a fundamentally stronger competitive position. Ultimately, taking this action is presented as a necessary step to reduce a known, measured risk and to secure Kraków Airport's long-term role as a strong, efficient, and growing economic engine for the entire region.

References

1. *eAIP Poland*. Available online: https://ais.pansa.pl/eAIPIFR/, 30.05.2025.
2. Eurocontrol (2023). *Pan-European Repository of Information Supporting the Management of EATM (PRISME) Database*. European Organisation for the Safety of Air Navigation. (Data used under specific agreement).
3. FAA (2024). *Runway Visual Range (RVR) Systems and Category Landing Minima: Technical Guidance (Report).* Washington, D.C.: Federal Aviation Administration.
4. Iowa State University Environmental Mesonet (2023). *Automated Surface Observing System (ASOS) Data for EPKK, 2015-2023.* Retrieved from: https://mesonet.agron.iastate.edu/, 30.05.2025.
5. Kwasiborska, M., Żak, B., Konopczak, K. (2023). Weather Conditions as Factors Disrupting Aircraft Operations at Polish Airports. *Sensors, Vol. 23, Iss. 4,* pp. 1375-1404. doi: 10.3390/s23041375.
6. Łupikasza, E., Niedźwiedź, T. (2016). Fog climatology in southern Poland (1966-2015). Bulletin of Geography. *Physical Geography Series, Vol. 11,* pp. 25-33. doi: 10.1515/bgeo-2016-0003.
7. Pilguj, N. et al. (2020). Trends and Variability in Low Visibility Events at European Airports. *Meteorologische Zeitschrift, Vol. 29, Iss. 5,* pp. 465-478.

8. Skomorowski, K., Piotrowski, T. (2018). Weather Conditions and Their Impact on Aviation Delays in Poland. *Transport Miejski i Regionalny, Vol. 12,* pp. 14-20.
9. Skrzyńska, K. (2019). Fog Occurrence and Aviation Safety at Kraków Airport. *Kraków University of Technology Reports, Vol. 23, Iss. 3,* pp. 112-124.
10. Zawadzka-Manko, E., Markowicz, K. (2025). Fog Frequency and Visibility Reduction Trends in Poland (1973-2020). *International Journal of Climatology, Vol. 45, Iss. 1,* pp. 47-52. doi: 10.1002/joc.7832.

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OPTIMIZATION OF THE FORMWORK RENTAL COST USING THE NIF METHOD TAKING INTO ACCOUNT THE VARIATION OF THE CROSS-SECTION OF THE MONOLITHIC ELEMENT

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Purpose: The aim of the work is to determine the optimal value of the cost of renting formwork for monolithic works, assuming a variable cross-section of the formwork elements.
Design/methodology/approach: The article attempts to analyze the optimization costs of leasing system formworks using the author's research method NIF (no idle formwork).
It is an extension of the classic parallel-stream methods - with continuous use of production means (no idle) and with uninterrupted work on the work front (no wait).
For the purposes of empirical research, selected structural elements of a sports hall building with a monolithic "foot-column" structure were used.
Findings: The implementation of the proposed NIF method proved that it allows for the selection of the numerical composition of the work team and the division of the work front into elementary plots, finding the optimal team work plan and implementation scenario in the set of admissible solutions, limited by the implementation deadline or cost budget.
Research limitations/implications: The essence of calculating the rental of system forms is to determine the required time of their stay on the work front, during assembly, technological standstill (the process of binding the concrete mix) and dismantling. The calculation of the costs of traditional forms, apart from the time of their assembly and dismantling, during which the costs of human work (labour) are incurred, treats the above principle in a different way: wood formwork material, purchased as a non-renewable resource, is treated in it at the purchase price - with standard recovery, and not at the cost of labour.
Practical implications: Construction formwork for monolithic works, due to its technological specificity, is divided into traditional – made of sawn wood, and system – supplied in the form of unified elements.
Social implications: System formwork forms for monolithic works, as their price-determining component, are cost-intensive equipment units, hence the appropriate selection of their quantity and determination of the lease period on the construction site is a very important issue, affecting the profitability of these works.
Originality/value: The innovative element of the work is the use of the proprietary NIF method, which determines the optimal level of construction formwork lease costs.
Keywords: formwork, cost optimization, schedule coupling.
Category of the paper: Research paper.

1. Introduction

Resource allocation management is one of the main planning problems (Przywara, 2022, 2025). Modeling involves modeling resources that, as a result of a detailed analysis, can be used to carry out the works covered by the schedule.

The issue of time and cost optimization of the rental of system formwork on the construction site was addressed mainly in relation to the search for methods to shorten the duration of works, which also results in a reduction of costs. The paper (Biruk, Jaśkowski, 2017) presents factors influencing the selection of various formwork systems for the construction of high-rise buildings, of which a total of forty were identified.

The analysis revealed that the main ones include the duration of the project, rental costs and the layout of the structure. The research was based on regression analysis to quantify the impact of factors on work efficiency. To determine the interdependencies between the studied factors, the Spearman correlation test was performed, which was intended to identify the independent variable having a significant influence on the selection of the formwork system.

Heuristics are also a popular tool in optimizing the time and cost of formwork. In the work (Kaveh, Behnam, 2012) heuristic algorithms were used for cost optimization in the implementation of ceiling systems, including their formwork. In order to optimally select the formwork, floor slabs with variable thicknesses and spans were considered. The proposed method has been described on three levels. The first is initialization, where elements are randomly selected for analysis. The second step is to search for the optimum that minimizes costs and provides a solution to the problem. The third level is the termination stage. The algorithm checks whether the criteria set by the operator meet the obtained results.

In the paper (Lee et al., 2014), the selection of formwork systems was analyzed by developing criteria for assessing their applicability by decision-makers implementing construction projects in Turkey, at various planning stages. The research results indicate a high level of agreement among participants in investment processes regarding the selection of a system based on criteria such as the degree of repeatability, speed of implementation, rental cost, and the possibility of reuse in subsequent projects. The paper draws attention to the continuous increase in formwork rental costs. A model of formwork arrangement using a genetic algorithm was presented in order to minimize the rental time and obtain the cost level as a solution close to the optimal one. The proposed model searches for the optimal formwork layout to maximize the proportions of modular forms by adopting twelve types of solutions for which positions and sizes are variable. The layout of the formwork forms and the positioning of the columns are determined according to the gene sequences. Based on the case study, the model showed a decrease in the share of formwork covering the surface by approximately 11.9%, while the cost of formwork rental decreased by 10.4%. This concept can also be used at the work planning stage to increase the efficiency of work teams.

Genetic algorithms were also the subject of the analysis of formwork rental costs in (Bhingarde, Bhusari, 2021), where their use was presented to determine the optimal solution for the design of ceiling and beam formwork while maintaining the minimum cost. In this case, the algorithm is activated after determining the gene structure and fitness function, and the gene population is subjected to evolutionary optimization. The first stage is the selection phase, where individuals are selected and reunited to produce new offspring. The aim of the selection is to provide the best adapted solutions. One-point and two-point crossover were used. Then, the normalized efficiency value of the obtained solution was calculated. During each iteration, the adopted reproduction operators determined the means to generate new, better solutions. In addition to crossover, mutation was also used, which is a method of introducing new variables into the gene pool.

The paper (Tierzoglu, Polat, Turkoglu, 2022) presents the results of research on the influence of the choice of formwork system on the time, cost and quality of monolithic works. The research drew attention to the contradiction of some criteria (e.g. time-cost), and the aim was to identify their different groups and analyze the relationships between them. The conclusion was drawn that many previous works ignored the quantitative interdependencies between the identified groups, which had a significant impact on the efficiency of works.

In the publication (Al-Ashwal, Abdullah, Zakaria, 2017), the authors analyzed the durability of traditional formwork and the possibility of its repeated use. Attention was drawn to the economic value of this solution and its simultaneous negative impact on the natural environment. The use of conventional formwork systems in carpentry work has been assessed as incompatible with sustainable economic development, encompassing not only economic but also social and environmental issues.

In the work (Ko, Kuo, 2012) it was indicated that formwork engineering is a key factor influencing the time-cost result of monolithic works. The research was conducted using the Kanban system (Lean Manufacturing method), and the optimization consisted in minimizing the costs of transporting formwork to the work front while simultaneously increasing the degree of their multiple use, through the repeatability of assembled forms.

The work (Baskova, Krajnak, 2013) concerns the influence of the factor of formwork lease time on its costs. The authors showed that the costs of construction formwork in Slovakia constitute 25–30% of the total costs of works, depending on regional differences in the prices of labor and materials. The proposed cost optimization consists in analyzing the number of working plots in the formwork of elements, with gradual shifting of formwork. The method focuses on minimizing the number of individual types of forms.

In (Li et al., 2022) a technique based on genetic algorithms for determining the optimal solution for the formwork design was presented. The formulated objective function takes into account the rental cost of formwork and estimated labour corresponding to the assembly of the forms. The principles of structural design of reinforced concrete elements were adopted as

constraints for the optimization problem. The developed method can be used to design ceiling formwork and high concrete elements.

Time Coupling Methods (TCM), which are sometimes referred to as Linear Scheduling Methods (LSM), were developed by Professor Viktor A. Afanasyev (Afanasjev, 2000, 2008). Using them, he analyzed the schedules of work implementation, assuming the division of the front into work plots of different sizes and the resulting different times of their implementation. Professor Afanasyev scientifically described the LSM (TCM) methodology, providing a workshop of their research tools. The most commonly used parallel-stream methods include: the method with continuous use of production means (no idle) and the method with continuous work on work fronts (no wait) (Hejducki, Mrozowicz, 1994; Przywara, Rak, Chyliński, 2015). The method with continuous use of production resources (no idle) combines subsequent works of one type, determining the degree of their continuity within each type of work (or the degree of continuity of resource use) – resources perform work without unnecessary interruptions. This method assumes zero coupling between the means of production:

$$T = \sum_{j=2}^{m} t_{rj} + \sum_{i=1}^{n} t_{im} \tag{1}$$

where:

t_{rj} – time interval between the start of the predecessor and the successor (assuming critical proximity, eliminating overlap of the work of the brigades) [r-h],

t_{im} – duration of the m-th type of work on the i-th construction work front [r-h].

The value of trj can be expressed by the formula [4]:

$$t_{rj} = \max_{k}\left(\sum_{i=1}^{k} t_{i,j-1} - \sum_{i=1}^{k-1} t_{ij}\right) \tag{2}$$

with: $k = 1, 2, \ldots, n$, $t_{0j} = 0$.

Changing the order of carrying out works on individual fronts does not affect the change in the duration of the last (mth) type of works, hence:

$$\sum_{i=1}^{n} t_{im} = const \tag{3}$$

Therefore, achieving the minimum development time of each type of work is achieved by reducing the development periods of the second and subsequent types of work:

$$T^{min} = \sum_{j=2}^{m} t_{rj(\min)} + \sum_{i=1}^{n} t_{im} \tag{4}$$

In turn, the method with continuous work on work fronts (no wait) combines subsequent works of different types, within each partial complex, defining the degree of continuity of occupation of partial fronts - there are zero couplings between work fronts. In this method, individual tasks are performed without breaks (Hejducki, Mrozowicz, 1994):

$$T = \sum_{j=1}^{m} t_{1j} + \sum_{i=2}^{n} t_{zi} \tag{5}$$

where:

t_{1j} – duration of the first partial set of works in the facility [r-h],

t_{zi} – time interval between the completion of the predecessor and successor on plot [r-h].

The value of t_{zi} can be expressed as:

$$t_{zi} = \max_{k}\left(\sum_{j=k}^{m} t_{ij} - \sum_{j=k+1}^{m} t_{i-1,j}\right) \tag{6}$$

with: $k = 1, 2, \ldots, m$.

The minimum duration of a set of works is obtained after determining the order in which they are to be carried out, in which the sum of the completion times of the first set and the winding times of the remaining ones is the smallest. The middle block of partial complexes has no influence on the time of completion of the complex of works (the complexes overlap each other). The classical methods of organizing construction projects described above and their popular extensions show a wide spectrum of planning possibilities in the design of various implementation solutions for production systems. In the search for optimization solutions that minimize the time spent by equipment units on the construction site, the most effective results are provided by the parallel-stream method no idle. In special cases, such as excess resources, it may, however, ignore the influence of the degree of occupation of work fronts.

2. The proprietary approach method (NIF) in optimizing the cost of formwork lease

2.1. Model of streamlined execution of works assuming parallel-stream method with continuous use of formwork (no idle formwork)

The proposed method essentially assumes the absence of organizational downtime in the formwork operation, classifying the cost-effectiveness of the process implementation by searching for the optimal division of its working front into plots (Figure 1).

Time values are expressed in machine hours [m-h], because they refer to the work of formworks as construction equipment, and not to work crews [r-g], the lack of downtime of which is assumed by the no idle method.

The implementation cycle of the analyzed *j-th* construction process in all its working plots ($i = 1, 2, \ldots, n$), taking into account the working operations that create it ($k = 1, 2, \ldots, p$) in the NIF method is calculated from the relationship:

$$T_{nj\,(NIF)}^{PW} = \sum_{i=1}^{n-1} \sum_{k=1}^{p} t_{ik} + t_{nj} \tag{7}$$

where:

t_{ik} – duration of the *k-th* work operation on the *i-th* work plot in the formwork operation,

t_n – duration of works on the last (n) working plot, for all work operations.

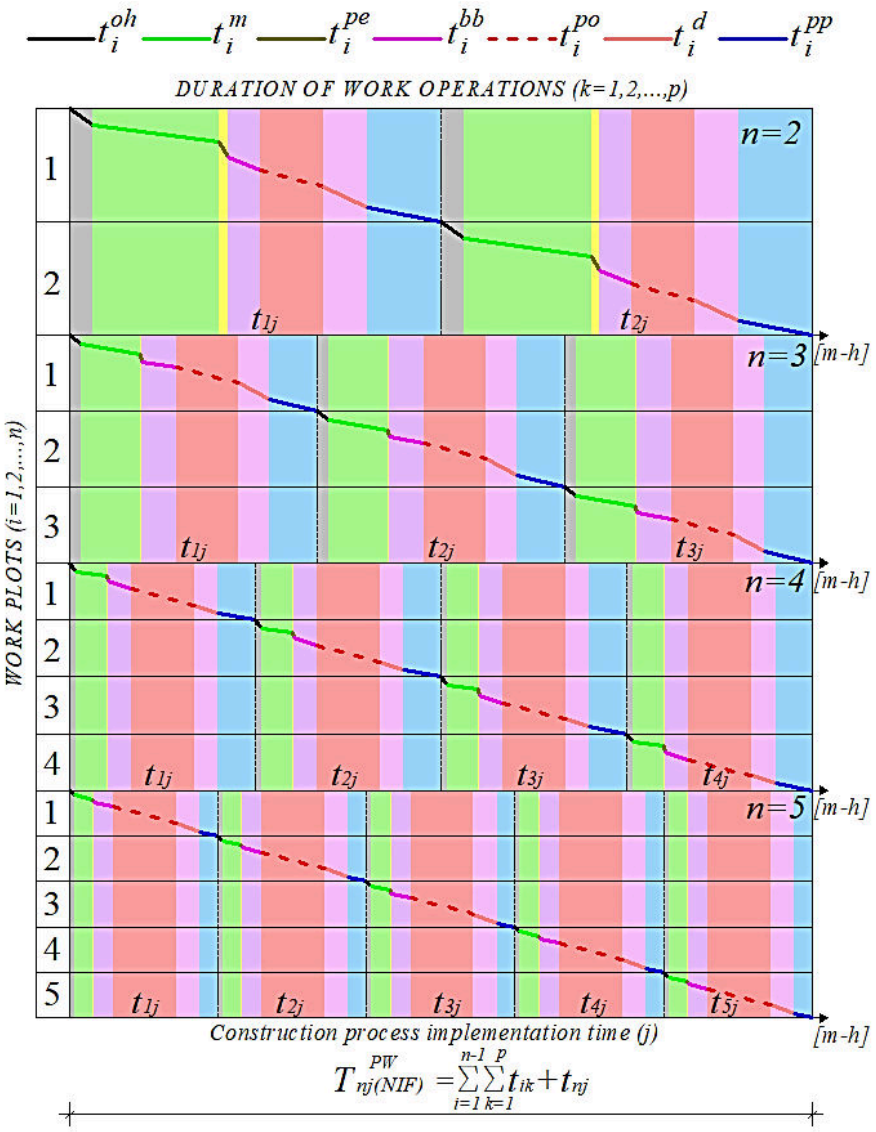

Figure 1. Generalized cyclogram of work operations (p = 7) of the construction process (j = 1) in the parallel-flow method with continuous use of formwork (no idle formwork) in four scenarios of division into working plots (i = 2, 3, 4, 5).

Source: Own study.

The value of tik can be expressed by the formula (with: $v = 1, 2, \ldots, n$, $t_{0i} = 0$):

$$t_{ik} = \min_{v}(t_{C\,(j)}^{(sp)} + t_{B\,(j)}^{(sp)}) = \min_{v} \sum_{i=1}^{n} \left(t_i^{oh} + t_i^{m} + t_i^{d} + t_i^{pp}\right) + n * p_{ij}^{d} \tag{8}$$

The technological downtime of formwork (p_{ij}^{d}) is a value independent of the number of working sections, but correlates with the number of repetitions (waiting for concreting: t_{ij}^{pe}, concreting of the element: t_{ij}^{bb}, binding of the mixture (technological downtime of formwork: t_{ij}^{po}).

In the case of the NIF method, the duration of works on the last (n) working plot, related to all its working operations, is a constant value, being the last "link" of the implementation flow:

$$\sum_{k=1}^{p} t_{nj} = const \tag{9}$$

Determination of the minimum development time of work operations on each work plot (except the last one) is achieved by minimizing them on the first and subsequent ones:

$$T_{(NIF)}^{min} = \sum_{i=1}^{n-1} \sum_{k=1}^{p} t_{ik}^{min} + t_{nj} \tag{10}$$

2.2. Description of the research model

In the implementation of the proposed NIF method, a research model was used in the form of a structural system consisting of eight reinforced concrete monolithic columns with variable cross-section (elements S-2/S-2'/S-2" – figure 2-3). The construction project of a school sports hall was carried out with the author's participation in 2009 in Przystajń (Silesian Voivodeship, Poland).

Figure 2. Research model: reinforced concrete columns S-2/S-2'/S-2".

Source: author's photographs.

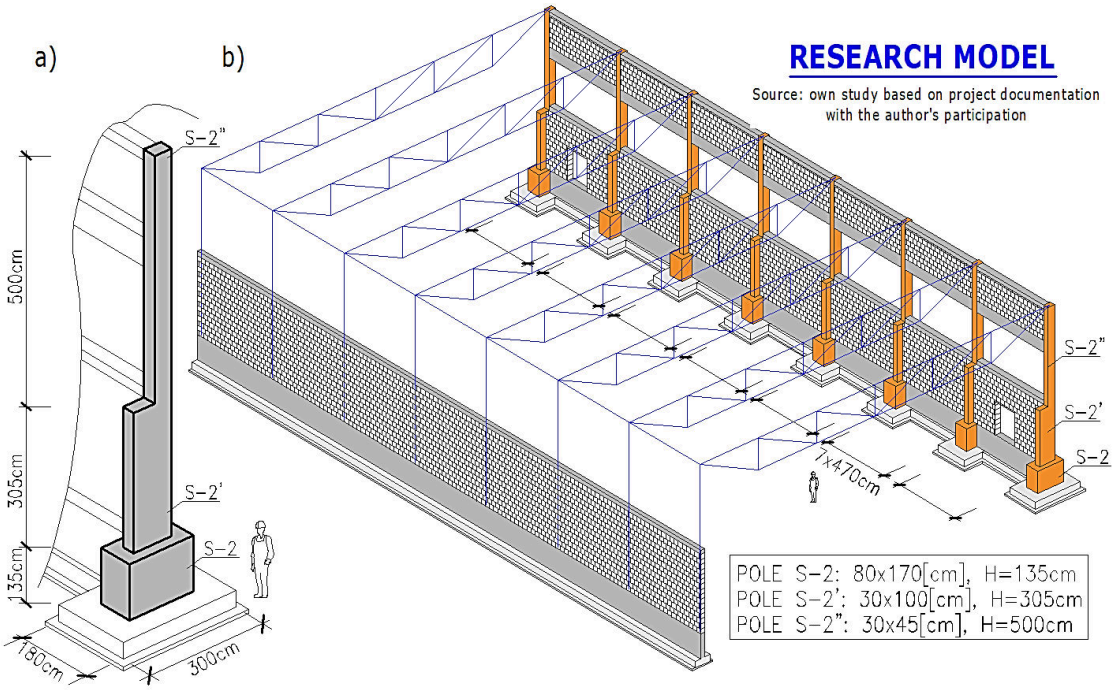

Figure 3. Research model for analysis: structural system of the sports hall: a) dimensions of the analyzed elements, b) axonometric view of the object (Przystajń/Kłobuck district/Silesian Voivodeship/Poland, description in the text).

Source: own study based on the design documentation of the object.

In the optimization analysis, a catalogue classification of the group of material outlays of individual column parts was made, making their implementation workload dependent on the ratio of the length of the formwork perimeter to the surface area of their cross-section. According to the table of standards 0269 of the KNR 0-20 catalogue ("Monolithic concrete and reinforced concrete structures in Peri formwork"), the following groups of outlays were categorised for the analysed element: "up to 6 m/m^2" (S-2), "up to 9 m/m^2" (S-2') and "up to 12 m/m^2" (S-2").

2.3. Application of the proprietary NIF method (no idle formwork)

Table 1 presents calculations of basic time and cost parameters of the analyzed monolithic element. Based on the standard formwork area per unit of structure measurement (P_{desk}^{jm}), the area of its complete set and the corresponding rental and labor costs of the work crew were determined.

Table 1.
Characteristics of the tested monolithic element: reinforced concrete column S-2 / S-2' / S-2"

Number of working plots	Standard surface area of a complete formwork set	Assembly and disassembly time: FORMWORKING	Formwork working time: FORMWORKING	**Formwork rental cost: (NIF)**	Brigade working time standards	The numerical composition of the work brigade	Assembly and disassembly time BRIGADE	**Cost of hiring a brigade: (NI)**
X [szt]	$P_{desk}^{kpl\ (X)}$ [m^2]	$T_{desk}^{M,D\ (X)}$ [m-g]	$T_{desk}^{P\ (X)}$ [m-g]	$K_{N\ (X)}^{desk}$ [pln]	$T_{rob}^{M,D\ (X)}$ / $^{JW=1}$ [r-g]	JW [os]	$T_{rob}^{M,D\ (X)}$ [r-g]	$K_{N\ (X)}^{rob}$ [pln]
POLE - Hi S-2: (formwork area per unit of measurement P_{desk}^{jm}=7,02 m^2/m^3)								
1	103,12	14,60	80,00	**3 642,78**	124,08	12	90,34	**36 316,54**
2	51,56		160,00	**3 361,65**	204,08	6	194,01	**38 996,54**
4	25,78		320,00	**3 221,08**	364,08	3	441,36	**44 356,54**
POLE - Hi S-2': (formwork area per unit of measurement P_{desk}^{jm}=13,61 m^2/m^3)								
1	99,63	14,26	80,00	**3 506,45**	121,01	12	90,08	**36 213,97**
2	49,81		160,00	**3 241,23**	201,01	6	193,50	**38 893,97**
4	24,91		320,00	**3 108,62**	361,01	3	440,34	**44 253,97**
POLE - Hi S-2": (formwork area per unit of measurement P_{desk}^{jm}=28,78 m^2/m^3)								
1	155,41	17,64	80,00	**5 666,05**	141,79	12	91,82	**36 909,80**
2	77,71		160,00	**5 154,26**	221,79	6	196,96	**39 589,80**
4	38,85		320,00	**4 898,36**	381,79	3	447,26	**44 949,80**

Standard technological downtime of formwork td = 10 days. Working day regime: tR = 8 m-h/day. Labor rate: Cjrob = 33.50 PLN/r-h, formwork: Cjn = 37.34 PLN/m-h/100 m^2 (according to Q3 2024). Implementation variant: II (use of a concrete pump). Pdeskjm value according to table 9906 (KNR 0-20).

Source: own study based on the design documentation of the object.

The column was divided into parts (S-2/S-2'/S-2") resulting from the variable dimensions of its cross-section. The optimization analysis assumed three scenarios of dividing the front into work plots (X=1/2/4) and the corresponding work plans, assuming a variable numerical composition of the work brigade (JW=12/6/3).

Figure 4 compares the unit cost of formwork rental and crew labor corresponding to the adopted scenario (X) and work plan (JW). The rental of formwork forms was related to their surface area (PLN/m^2), while the labor cost was related to the formwork quantity per volume of the formed element (PLN/m^2/m^3). The obtained values indicate that the increase in the number of working plots (X) is accompanied by higher unit labor costs of the work team – despite its decreasing numerical composition (JW), and decreasing formwork rental costs.

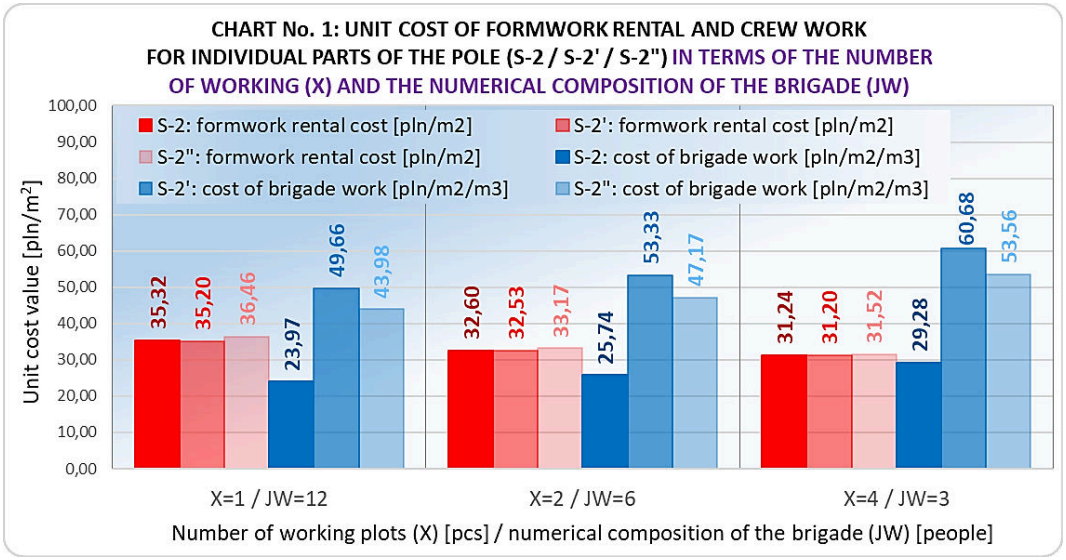

Figure 4. Unit cost of formwork rental and crew work for individual parts of the pole (S-2/S-2'/S-2").

In this case, the analysis showed an increase in production labour costs by 7.20-7.40%, with a decrease in the share of formwork forms by 7.70-9.00% (for X=1/JW=12, X=2/JW=6). This trend is also maintained by the second change of the scenario and work plan (X=2/JW=6, X=4/JW=3), although the greater dynamics of changes in the crew costs (13.60-13.80%) is accompanied by a smaller amplitude of the formwork lease costs (4.20-4.98%). Moreover, the growing value of the column perimeter-cross-section ratio (m/m^2) is accompanied by a slight decrease in the formwork rental costs (S-2/S-2': 0.10-0.30%) – with dynamically increasing team labour costs (by 107.20%). The second change in the column dimensions (S-2'/S-2") generates an inverse relationship – a decrease in the labor costs of the work crew (11.44-11.73%), with an incomparably smaller increase in the cost of renting formwork (1.03-3.60%). The study therefore leads to the conclusion that wide analysis ranges containing groups of column implementation costs (perimeter-cross-section ratio) may include in their extreme values various monotonicity of cost increase, depending on its dimensions, which result from static and strength calculations.

The following figures (No. 5-7) present the results of cost optimization of carpentry works of the tested monolithic element – in the aspect of selecting the numerical composition of the brigade (JW) carrying them out and the degree of division of the front into plots (X): in the case of limiting the set of permissible solutions in the form of an imposed directive deadline. The optimization analysis using the proposed NIF (no idle formwork) method indicates its logical response to the given organizational conditions regarding the staffing of the work front (JW) and the adopted set of formwork forms for one-time formwork (X). The results of empirical studies were compared for the value of total costs of carpentry work (team work and formwork rental).

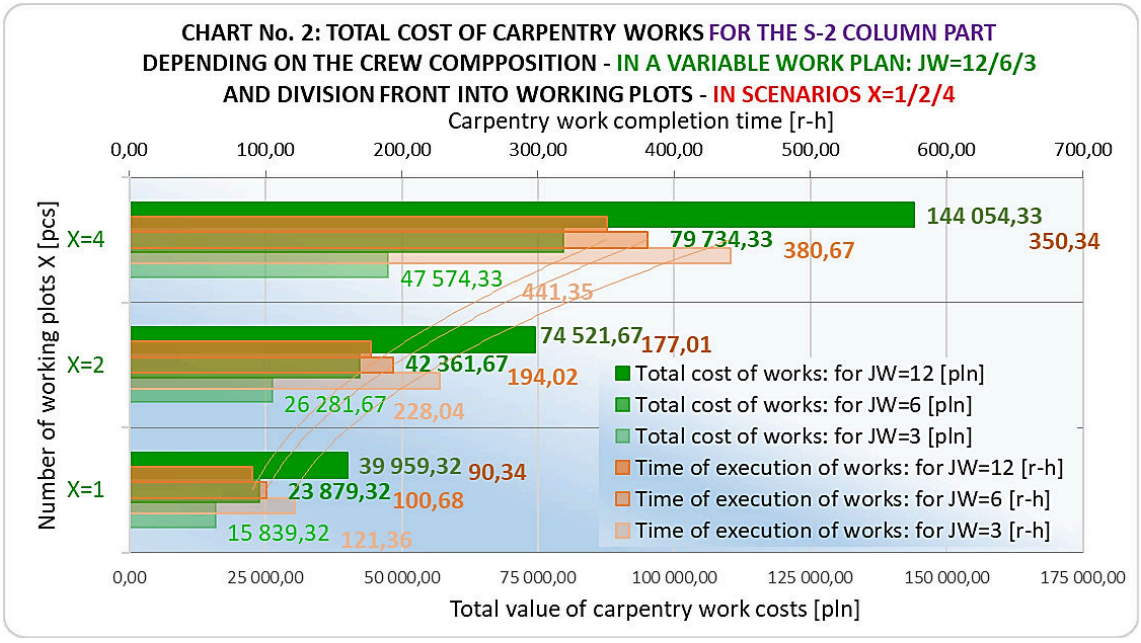

Figure 5. Total cost of carpentry works for the S-2 column part.

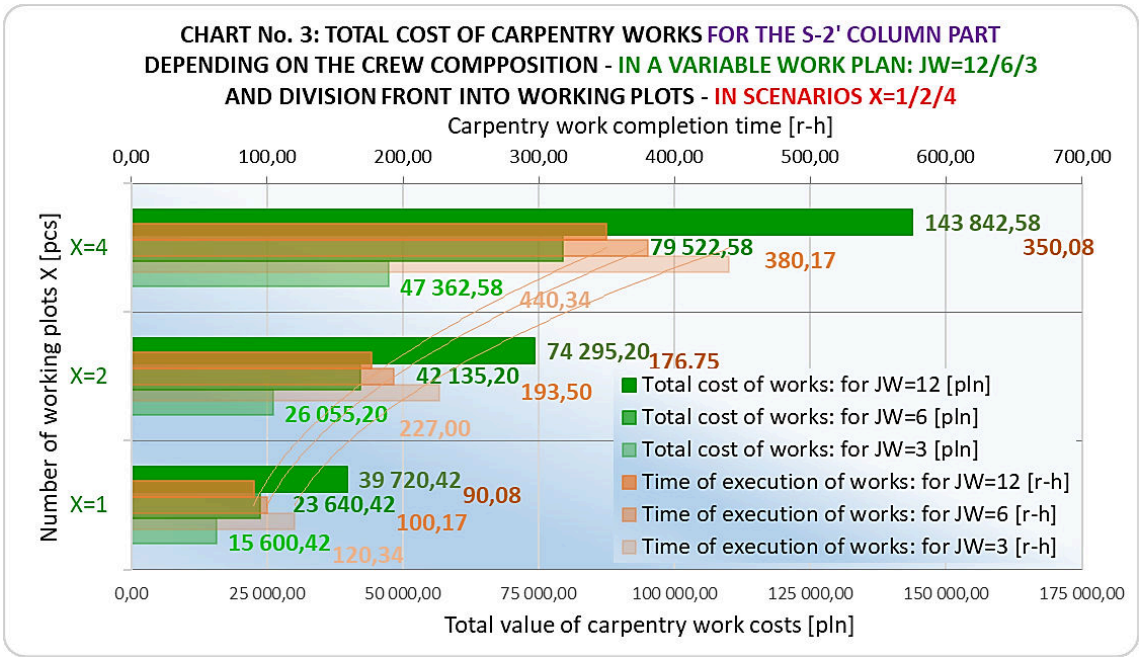

Figure 6. Total cost of carpentry works for the S-2’ column part.

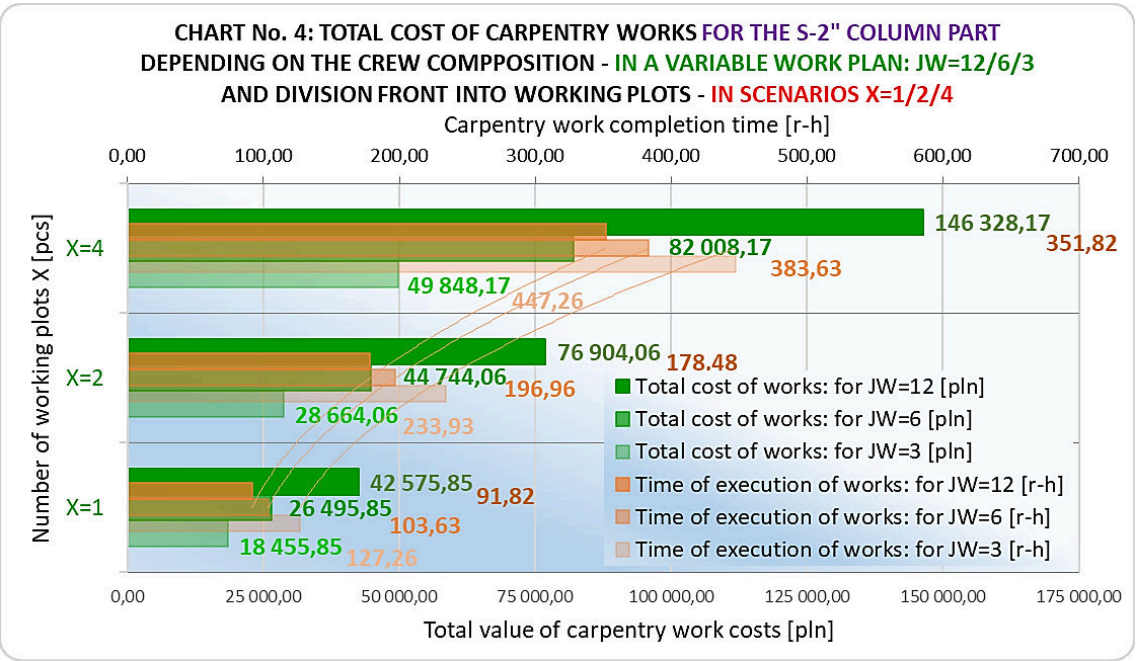

Figure 7. Total cost of carpentry works for the S-2" column part.

For each of the analyzed parts of the column (S-2/S-2'/S-2") – in all implementation scenarios (X=1/2/4) – the reduction of the duration of works, consisting in supplying the brigade with an additional stream of production means (JW=3/6/12), resulted in an increase in costs. In the case of the S-2 column part (figure 5), which falls within the group of costs meeting the value range of "up to 6 m/m^2", the largest dispersion of the values of time and cost of works was obtained for the implementation scenario X=4: doubling the composition of the brigade (JW=6/12) results in a shortening of the implementation time by 8.00%, with an increase in costs by 80.7%. The next scenarios – X=2, X=4 – correspond to increasing, in absolute value, time reductions (by 8.80%, 10.30%, respectively) with lower cost increases (75.90% (X=2), 67.30% (X=4)).

The analysis of the values obtained using the NIF method for the S-2' column section (figure 6 outlay group "up to 9 m/m^2") shows similar relationships. The most effective, from the point of view of the time of carpentry work, is the simultaneous formwork of the entire work front (X=1) – with maximum team power (JW=12). The reduction of the brigade to JW=6 corresponds to a 59.75% decrease in work costs and a simultaneous extension of their duration by 11.45%. The third work plan (JW=3) reduces implementation costs by 34.00% - with its time extension by 20.14%. The subsequent work implementation scenarios (X=2, X=4) are characterized by lower formwork rental costs and higher team labor costs, which ultimately translates into an increase in their total values. However, such optimization does not take into account the issue of limited access to production resources (workers and formwork molds), which translates into the need to select the best solution from the set of acceptable solutions, constituting the essence of the proposed NIF method.

Figure 7 presents the results of the optimization analysis for the S-2 column section". The determined time and cost values are characterized by the analogy of the obtained dependencies in this case, in comparison with the S-2 and S-2' column sections. In the case of a work organization scenario covering the entire front simultaneously (X=1), reducing the number of working teams by half (JW=12/6) generates an extension of their duration by 12.86%, with a simultaneous increase in costs by 37.77%. Further reduction of the team composition (JW=6/3) causes their implementation in a longer time by 22.80%, thus reducing the total costs of the works by 30.34%. The comparison of the values obtained for the three parts of the column (S-2/S-2'/S-2") shows a constant trend: decreasing the dispersion of the percentage values of the time and cost of carpentry work, along with the increasing value of the perimeter-to-cross-section ratio ("up to 6/9/12 m/m^2") assigning the element to different catalogue groups of material outlays. This dependence results from the increasing labour intensity of making the column formwork, related to the production unit (m3) – along with the increasing slenderness of the element. It is also worth noting that in each of the assumed implementation scenarios (X) both time and cost values do not show linear dependencies. The total cost of leasing the formwork for the examined column, in each of the analysed scenarios (X), shows an upward trend, regardless of the accompanying systematic reduction in the number of the crew (figure 8).

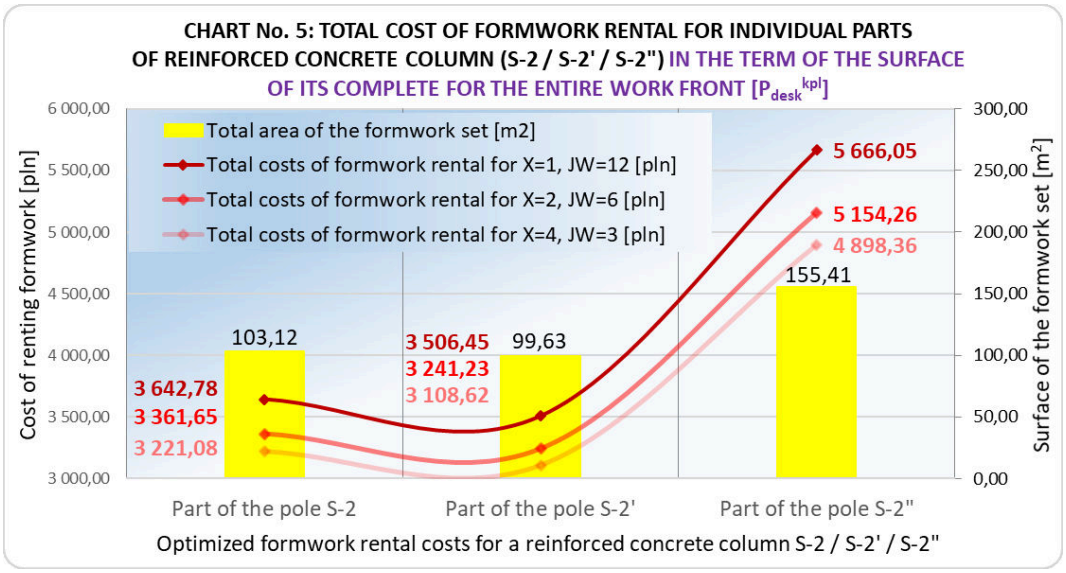

Figure 8. Total cost of formwork rental for individual parts of reinforced concrete column (S-2/S-2'/ S-2").

The highest cost values were obtained for the implementation scenario X=1: with the area of the required set P_{desk}^{kpl}=103.12 m^2, the lease of formwork forms is 8.36% more expensive than the option including the division of the front into two working plots (X=2). Increasing the number of plots to four (X=4) results in costs being 4.18% lower compared to the second scenario (X=2). The second part of the column (S-2': P_{desk}^{kpl}=99.63 m^2) is characterized by a lower value of the total cost of formwork lease – and slightly lower variability in the transition between subsequent scenarios. For X=1/2, a 7.56% decrease in their value was obtained, while

for X=2/4: 4.09%. The largest area of the formwork set (P_{desk}^{kpl}=155.41 m^2), relating to the column part with the greatest slenderness (S-2”: the ratio of the perimeter to the cross-section of the element "up to 12 m/m^2") is characterized by the highest value of the amplitude of the increase in total costs. For the transition between the implementation scenarios X=1/2, a jump of 9.03% was recorded, and by 4.97%, respectively – with their change X=2/4. The optimization analysis of the formwork rental cost, taking into account the time of carpentry work and the variability of the cross-sectional dimensions of the monolithic element, shows a tendency for the costs to increase with its increasing slenderness.

As shown in Table 1, the categorization of individual parts of the tested column into one of the catalog effort groups ("up to 6/9/12 m/m^2") - with a decreasing value of the formwork assembly and disassembly time standards ($m\text{-}h/m^3$) generates an increase in the formwork area per unit of structure measurement (P_{desk}^{jm}: m^2/m^3). The adopted research model (Figure 2) contains elements of different, increasing heights (S-2: 1.35 m, S-2’: 3.05 m, S-2”: 5.00 m). Assuming in the analysis the average height of the column over its height (S-2 = S-2’ = S-2” = 3.13 m) would give a linear relationship of decreasing – with increasing slenderness – total formwork rental costs with their increasing values, related to the volume of the formed element (pln/m^3).

3. Conclusions from the conducted analyses

The optimization of the rental cost of formwork for carpentry work is justified when a directive implementation deadline is imposed on them. The proposed NIF method takes into account both the duration of the works and their cost. It also allows for the selection of the numerical composition of the work team and the division of the work front into elementary sections, finding the optimal team work plan (JW) and implementation scenario (X) in the set of admissible solutions, limited by the implementation deadline or cost budget.

The optimization analysis carried out, taking into account the variability of the cross-section of the monolithic formwork element, shows the correct dependencies of the increasing costs of formwork forms - with the increasing massiveness of the element (decreasing slenderness), and a simultaneous decrease in the value of unit costs. Similarly in the case of the analysis of time variables – the increasing numerical composition of the work team and the decreasing number of work sections are accompanied by their shortening.

References

1. Afanasjev, V.A., Afanasjev, A.V. (2000). *Potocnaja organizacja rabot v stroitelstwie*. Sankt-Petersburg.
2. Afanasjev, V.A., Afanasjev, A.V. (2008). *Stream methods in construction work*. Sankt-Petersburg.
3. Al-Ashwal, M.T., Abdullah, R., Zakaria, R. (2017). Traditional formwork system sustainability performance: expert's opinion. *Materials Science and Engineering*.
4. Baskova, R., Krajnak, M. (2013). An analytical approach to optimization of the cost for construction formwork. *Surveying Geology & Mining Ecology Management (SGEM).*
5. Bhingarde, R.P., Bhusari, J.P. (2021). Optimization of slab and beam formwork using genetic algorithm. *IOSR Journal of Engineering, vol. 11, Iss. 9*.
6. Biruk, S., Jaśkowski, P. (2017). Optimization of vertical formwork layout plans using mixed integer linear programming. *International Journal of Civil Engineering*.
7. Hejducki, Z., Mrozowicz, J. (1994). Harmonogramowanie pracy brygad roboczych z wykorzystaniem metody równoległo-potokowej z ciągłym prowadzeniem robót na obiektach budowlanych. *Scientific Papers of the Silesian University of Technology, Series: Automation, 115*.
8. Kaveh, A., Behnam, A.F. (2012). Cost optimization of a composite floor system, oneway waffle slab, and concrete slab formwork using a charged system search algorithm. *Scienta Iranica, Transactions A: Civil Engineering, 19(3).*
9. Ko, H.-HC., Kuo, J.-D. (2012). Making formwork construction lean. *Journal of Civil Engineering and Management, Vol. 21(4)*.
10. Lee, D., Lim, H., Kim, T., Kang, K.I. (2014). *A formwork layout model based on genetic algorithm.* The 31st International Symposium on Automation and Robotics in Construction and Mining, (ISARC).
11. Li, W., Bao, W.D., Lin, X., Xie, Y.M. (2022). A review of formwork systems for modern concreto construction. *Structures, Vol. 38*.
12. Przywara, D. (2022). Błędy przy deskowaniu elementów monolitycznych – studium przypadku. *Przegląd Budowlany, marzec-kwiecień*.
13. Przywara, D. (2025). *Deskowania budowlane. Analiza kosztowa w potokowej realizacji robót.* Scientific monograph. Publishing House of the Opole University of Technology.
14. Przywara, D., Rak, A., Chyliński, P. (2015). *Analiza czasu trwania przedsięwzięcia z uwzględnieniem sprzężeń czasowych między procesami produkcyjnymi*. Publishing House of the Warsaw University of Technology.
15. Terzioglu, T., Polat, G., Turkoglu, H. (2022). Formwork system selection criteria for building construction projects: a structural equation modeling approach. *Buildings*.

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MAPPING THE LANDSCAPE OF SMART ENERGY SYSTEMS (SES): INSIGHTS FROM BIBLIOMETRIC AND STATISTIC ANALYSIS FOR ENVIRONMENTAL MANAGEMENT

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Purpose: The objective of the article is to map the global research landscape on Smart Energy Systems (SES) between 2020 and 2024 by identifying dominant scientific trends, thematic clusters, collaboration networks, and emerging research topics.
Design/methodology/approach: The research employs a quantitative design, combining bibliometric analysis and statistical methods. A total of 11,609 publications were retrieved from the Scopus database, focusing on SES-related keywords. Bibliometric mapping using VOSviewer was conducted to analyze keyword co-occurrences, country collaborations, and author networks. Statistical visualization, including bag plots, was used to identify outliers and trends in keyword usage, highlighting both prevalent and emergent areas of research.
Findings: The analysis revealed six major clusters of SES research, including smart power grids, renewable energy integration, energy management systems, optimization techniques, and emerging digital technologies like IoT and blockchain. Dominant keywords included "smart power grids" (3572 occurrences), "electric power transmission networks" (2856), and "renewable energy resources" (1629). Outlier analysis indicated that future directions in SES research are closely linked to blockchain, machine learning, and green hydrogen.
Research limitations/implications: The study offers actionable insights for policy-makers, business leaders, and industrial stakeholders. Policymakers should prioritize regulatory frameworks promoting digitalization and interoperability of energy systems. Industry actors are encouraged to invest in IoT-enabled energy infrastructure, AI-powered decision-making tools, and peer-to-peer energy platforms. SES development is also strategically relevant for national climate goals, economic modernization, and industrial decarbonization.
Originality/value This paper is the first to offer a cross-sectional, global bibliometric and statistical mapping of Smart Energy Systems research in the post-COVID-19 era (2020-2024). It goes beyond traditional bibliometric studies by integrating quantitative visual analytics (bag plots) to reveal latent structures and trends. The article also introduces a typology of emergent research areas and provides practical guidance for aligning SES innovation with environmental and industrial policies.
Keywords: smart energy systems (SES); bibliometric analysis; renewable energy sources (RES).
Category of the paper: research paper.

1. Introduction

Advancements in areas such as artificial intelligence, blockchain, and the Internet of Things (IoT) are opening new opportunities in energy systems, creating Smart Energy Systems (SES). Intelligent electric grids rely on advanced technologies such as monitoring and control systems, sensors, smart meters, energy management systems, and advanced data analysis algorithms (Mohammadi et al., 2018). The collection, processing, and analysis of this data allow for a better understanding and control of the power system. Intelligent electric grids offer many benefits for consumers, grid operators, and society as a whole. Primarily, they enable better utilization of available energy resources through the optimization of distribution and the use of renewable energy sources (Dincer, Acar, 2017). Thanks to the ability for bidirectional energy flow, consumers have the opportunity to both draw energy from the grid and feed excess energy back into the grid, thus improving energy efficiency (Anjana, Shaji, 2017; Crossley, Beviz, 2010). There is an increase in consumer engagement in producing renewable energy. New forms of consumer energy initiatives are emerging in the market, such as energy cooperatives (Gajdzik et al., 2024a). In the global climate policy, solutions in SES can be used in strategies of industrial decarbonization based on renewable energy sources (RES) and universal access to energy (Nagaj et al., 2024; Razmjoo et al., 2022; Gajdzik et al., 2024b, Kvasničková et al., 2023). Development of the SES requires broad cooperation (partnership) at many levels of economies, industries and societies (Zhou et al., 2025).

The management of variable renewable energy sources, energy conservation, and renewable energy sources are receiving an increasing amount of attention. Although significant emphasis should be made on encouraging power savings, integrating variable renewable energy sources into the electrical grid in order to reduce emissions is receiving more attention (Ryu et al., 2014; Mason et al., 2010; Khalid, 2024; Elliston et al., 2012; Krajačić et al., 2011).The rising need for smart energy systems originates from the growing acceptance of renewable energy sources, growing consciousness around energy conservation, and the anticipated rise in energy expenses and waste (Xu et al., 2020; Gajdzik et al., 2023d, 2024c; Gajdzik et al., 2025). Numerous studies exist on the bibliometric analysis of the smart energy system issue, but they typically focus on a specific country (Wang et al., 2020; Gajdzik et al., 2023b), management innovations within the smart energy system domain (Ali et al., 2021; Wang et al., 2022), or renewable energy systems (Rosokhata et al., 2021; Ionescu et al., 2022; Gajdzik et al., 2024b; Lund et al., 2017; Pan et al., 2023; Edgar, Pistikopoulos, 2018). In management, the emphasis is primarily on the application of intelligent technologies to the autonomous optimization of industrial processes, especially in highly energy-intensive industries (Gajdzik et al., 2021).

The primary goal of this paper is to provide a comprehensive analysis of the current state and emerging trends in research related to Smart Energy Systems (SES). The paper aims achieving following objectives:

- To elucidate the structure and dynamics of the SES research field, including key research clusters, as well as mapping their components to understand the SES in global space.
- To highlight emerging trends and significant developments within the SES domain. This includes analyzing keyword patterns and research focus areas to pinpoint novel concepts, innovative technologies, and evolving methodologies that are shaping the future of energy systems.

Authors analyzed data from 2020-2024: bibliometric analysis. The academic website Scopus was main source of scientific publications in authors' research in smart energy systems (SMS). 11,609 research publications published between 2020 and 2024 have been included in our analysis. The title, abstract, and keywords sections provide search materials related to the "smart", "energy", and "systems" topics. Using a content analysis, we looked at the most frequently used terms and their associations in order to show the structure of the scientific area. A network of co-occurrences was further considered. VOSviewer was used to carry out the analysis. Results of this analysis were cooperation networks and keywords clusters for two scopes of analysis. First scope for 128 keywords and second for 87 keywords. Moreover, the results of Scopus database analysis was used as a basis of statistical analysis using bag plots. To investigate the important data that the world's clouds provide in order to address the following primary research questions (RQs):

- RQ1 - What are the key scientific trends, concepts, and thematic clusters in the global research landscape on Smart Energy Systems (SES) between 2020 and 2024?
- RQ2 - What are the emerging topics and outlier keywords that descriptive directions of SES research in the Scopus database between 2020 and 2024?

2. Literature review

The term "Smart energy system" (SES) is contend with smart energy and it is a part of sustainable energy systems. The term "smart energy" originated from the term "smart earth" proposed by International Business Machines Corporation (IBM) in 2009 (Crossley, Beviz, 2010). The initial concept of sustainable energy systems was introduced by Lund, Andersen, Østergaard, Mathiesen, and Connolly (2012). They stated that, when considering the electricity sector as a component of a larger sustainable energy system, more cost-effective and better solutions for smart grid applications can be found than when considering the sector as a stand-alone entity. As a result, using a sustainable strategies rather than a smart grid approach that focuses just on power would be beneficial. This explanation was improved upon and revised as sustainable energy systems gained more attention in the paper (Lund, 2014) and (Lund et al., 2017). The concept of sustainable energy has emerged, encompassing the entire process related

to energy, from sources of acquisition, through various types of power plants and methods of delivering energy to consumers, to issues related to its efficient management (Yang et al., 2010; Bossel, 2005).

Now about “smart” in SMS. Smart means Self-Monitoring, Analyzing, and Reporting Technology (Xu et al., 2020; Zhang et al., 2024). The goal of the Smart Energy System (SES) is to combine the transportation, heating, and electrical sectors with a range of storage options—whether hourly, daily, seasonal, or biannual—to provide the flexibility required to include significant penetrations of variable renewable energy (Koutra et al., 2018). SES is a whole, and therefore the overall efficiency of systems must be optimized through interconnections between systems and the capabilities of Fourth Industrial Revolution technologies (Koutra et al., 2018; Khatua, 2019; Wolniak et al., 2020, Zhu et al., 2022). These energy systems, in line with climate policy, must incorporate renewable energy sources (RES), but most renewable sources (e.g., solar and wind energy) are intermittent, and consumer energy demand also experiences significant fluctuations (Aghamolaei et al., 2018). Smart energy system is not simply a combination of various sources of energy and subsystems (infrastructure, data, information technology, IoT etc.) but is subject to complex interactions inside and outside. Global optimization and cross-sector integration of the whole energy system are highly prioritized in the sustainable development of economies and industries.

According to Lund et al. (2012) the term "Smart Energy Systems" has frequently been used interchangeably with "Smart Grid," particularly in the context of control management. It also denotes that the control system in question has applications extending beyond just the electricity sector. Lund et al. (2017) aim to recognize the concept of smart energy systems, which integrate multiple energy sectors to create a comprehensive strategy for sustainable energy solutions (Bibri et al., 2017). The construct of SES concept is a form of model for various sectors (transportation, industry, buildings, heating and cooling, as well as electricity). Based on a literature review, these authors conclude that current scientific knowledge indicates that solutions for integrating renewable energy are focused within the boundaries of energy subsectors, relying on concepts such as "smart grid", "zero-energy buildings", and "thermal energy". Meanwhile, the industrial sector and the heating and cooling sectors have largely been overlooked. These authors believe it is crucial to highlight in descriptions of smart energy systems the advantages of transitioning from a single-sector approach to integrating the entire system into ecosystem systems (Lund, 2014; Lund et al., 2012, 2017). The SES system is created by main system of energy production (centralized energy production, three major energy networks, energy hubs, energy-using departments, and energy storage) and system of infrastructures with tree pillars: smart grids, smart heat networks, and smart fuel networks. Energy hubs link energy networks and regional energy use, distribution, and storage (Lund et al., 2017). These solutions are supported by computer management systems and smart technologies. The system nodes are end-use energy sectors including construction, transportation, and industry in addition to all energy sources and energy networks.

Smart energy systems (SES) with data and information technology support are seen to be promising options for energy system integration (ESI) in order to achieve a low-carbon and sustainable energy transformation (Ionescu et al., 2022; Lund et al., 2012). Based on the principles of cross-sector integration and whole system optimization, SESs regard smart grids, smart heat networks, and smart fuel networks as the three pillars (Lund et al., 2017; Zheng et al., 2023). In order to optimize smart energy systems, Mohammad et al. (2018) presented the idea of an energy hub and examined its uses in a variety of contexts, including dwelling, business, and industry. Østergaard (2015) elaborated on advanced performance indicators and assessed the use of the Energy PLAN model in smart energy systems. Bahramara et al. (2016) addressed the equipment model and optimization process in her study of the HOMER model's use for optimizing renewable energy systems. After reviewing the use of the particle swarm optimization (PSO) and genetic algorithm (GA) in hybrid energy systems, Fadaee et al. (2012) found that these two optimization techniques were most often used in hybrid energy systems. Suganthi et al. (2015) examined the use of fuzzy logic in the optimization of several renewable energy subsystems and suggested appropriate fuzzy logic for each. Smart energy systems are increasingly based on microgrids. EU policy provides funding for microgrid projects (MORE MICROGRIDS project, CRODIS). Microgrids are modern distribution systems that can reduce emissions, improve power quality, and reduce the cost of heat and electricity supply. Energy conservation and its diversification is one of the main aspects of management.

In the context of management, Mbungu et al. (2020) investigate the application of smart metering technologies in the energy management system for residential microgrids. Smart grids contribute to reliability and security of energy supply. Thanks to the ability to monitor in real time and quickly detect failures, it is possible to react immediately and minimize disruptions to the power supply. In addition, intelligent energy management systems enable flexible load sharing and remote control of the grid, which contributes to a better balance in the electricity system. The authors propose a dynamic system that can maximize energy flow and guarantee efficient power supply through intelligent energy resource management. Such a system can also adapt to the functions and types of households in a given energy system. The authors (Mbungu et al. (2020) create a system that simulates a smart metering framework to gather information from various parts of the electrical system, such as energy storage and solar systems connected to the grid. To regulate energy flow based on demand response and energy prices, they proposed three optimal control scenarios utilizing linear and quadratic techniques. The research indicates that incorporating green hydrogen into intelligent energy systems may considerably enhance energy economy, minimize expenses, and diminish greenhouse gas emissions. According to the simulations, hydrogen has significant advantages for energy storage and the integration of renewable energy sources, improving the overall sustainability of community-scale energy systems. The research indicates that by optimizing the use of energy storage and solar systems, the proposed energy management system can significantly reduce energy costs and improve energy savings. The trial results confirm that the technology is reliable and effective in

enhancing energy efficiency for residential applications. A smart energy system integrates many participants in the energy chain, from raw material suppliers and energy producers from various sources to consumers. In this integration, blockchain technology plays a helpful role by improving data and transaction management through applications such as peer-to-peer energy trading, grid enhancement, and electric vehicle support. Blockchain technology increases security, ensures better data privacy, data transparency, ubiquitous solutions, and greater data availability (Erturk, 2019). In order to create a synergistic in the SES, the system combines many sectors, including concentrated energy supply, industry, construction, and transportation (Md Shopan Ali et al., 2024).

Summary of the Literature Review on Smart Energy Systems (SES):

The literature on smart energy systems highlights several key areas:

- Focus on "Smart": This refers to the intelligence of the energy system, particularly its performance in terms of control, automation, and efficient management.
- Focus on "Energy": Emphasizes the use of renewable and diversified energy sources, aiming for a cleaner and more sustainable energy mix.
- Focus on "System": Highlights the integration of various subsystems into a unified structure. The core idea of a smart energy system is the seamless integration of multiple energy sectors, such as electricity, heating, and transportation.

The "smartness" of a smart energy system is primarily defined by the extent of system integration and the sophistication of its management processes. In the evolution of energy systems, SES represents the most advanced and holistic form.

3. Research methodology

In the manuscript we used the analysis of papers about SMS. Our research part of this manuscript consist of two part: bibliometric analysis and statistical analysis. The academic website Scopus was our main source of scientific publications, and we employed bibliometric analysis to identify the most relevant research in smart energy systems. 11,609 research publications published between 2020 and 2024 have been included in our analysis. The title, abstract, and keywords sections provide search materials related to the "smart", "energy", and "systems" topics. Our analysis consisted of two methods: the first stage – bibliometrics, the second stage – statistics. VOSviewer was used to carry out the bibliometric analysis. This computer program can create maps with numerous publications, maps with multiple items, maps of nations, publications, journal maps based on networks (co-citation). Moreover, it can create term maps based on common networks. In our analysis we used this program to present the co-authorship networks, keyword co-occurrence networks, and country collaboration networks, as well as to perform cluster analysis and visualize the structure of the scientific

research landscape in smart energy systems. The 160 keywords were used. Bibliometric analysis consists of four steps. Step 1: Search criteria in Scopus database (get articles base on most citied and newest researcher for each keywords). Step 2: Data collection (export Scopus database to import in VOSviewer for further analysis). Step 3: Group categorising (classification and clustering related keywords in VOSviewer). Step 4: Interpretation of results for each networks of analyses. In the second part of our research about SES we used statistical analysis. The method consists of four steps: Step 1: Data Collection and Pre-processing. Step 2: Construction of bag plots. Step 3: Analysis of keyword occurrence and link strength. Step 4: Identification of outliers and emerging trends.

4. Results and discussion

Results of bibliometric analysis are presented in the forms of networks, which allowed to establish clusters in the studied areas. Figure 1 shows co-occurrence and all key words with a number of occurrences of keywords 200. During this stage of analysis, 128 all key words were generated. Figure 1 shows six clusters (color: green, blue, red, yellow, violet, azure). The dominant words in the blue cluster are the words Smart Power Grids, Electric Power Transmission, Renewable Energy Resources (RES). The green cluster is dominated by the words Energy Efficiency, Energy Utilization, Internet of Things. The red cluster is dominated by the words Renewable Energy with different sources according to climate policy. The yellow cluster is dominated by the words Optimization and Costs. The violet cluster is dominated by the words Energy Storage with different solutions. The azure cluster is dominated by the words Power Markets, Blockchain.

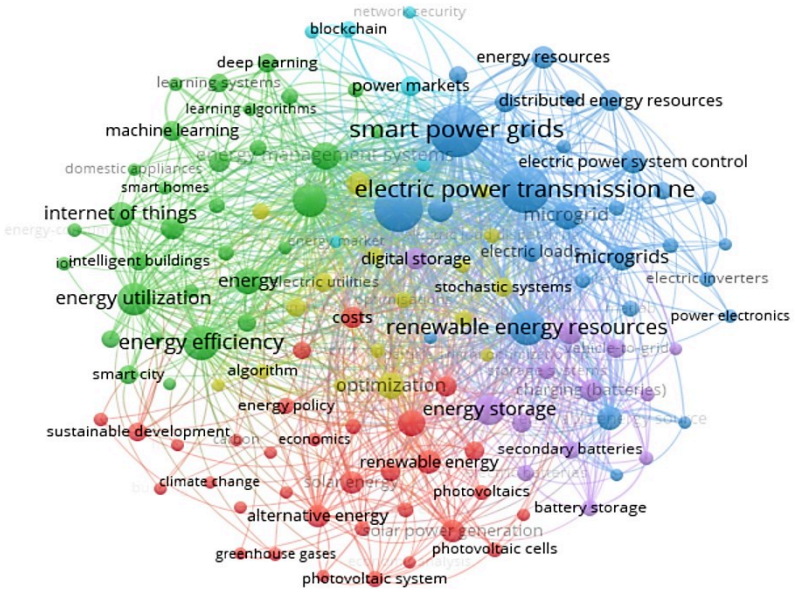

Figure 1. Word cloud for the co-occurrence - all key words (number of occurrence of keywords 50). Source: own elaboration based on bibliometric analysis of papers in Scopus database.

Bigger words (Figure 1) stand out more in the visual depiction because they suggest a greater frequency of occurrence. "Smart Power Grids", "Energy Power Transmission", "Energy", "Energy storage", "Energy Efficiency", and renewable energy resources“ are among the most recognizable words. These phrases draw attention to the research's main areas of emphasis. Based on the analysis the key studies are "Smart Grids", "Renewable Energy", and "Energy Power Transmission." This graphic highlights a significant body of research on the integration of renewable energy sources in SES.

Figure 2 depicts a word cloud for co-occurrence, including author key words. Each word's magnitude in the cloud represents its frequency of occurrence as a keyword; bigger terms are more prevalent. The research's primary areas of concentration are highlighted by prominent phrases such as "Smart Grid", "Renewable Energy", "Energy Management", and "Energy Efficiency". A substantial amount of the word "Internet of Things (IoT)" also occurs, implying that IoT technologies are essential to the creation of smart energy systems. The word "optimization", which refers to initiatives meant to improve these systems' effectiveness and performance, is another crucial one. Clusters of similar terms, such as "Smart Grids", "Renewable Energy", "Energy Management", and “Demand Response” may be shown in the figure 2. The word cloud suggests that integrating renewable energy sources, effectively managing energy resources, and enhancing sustainability (demand response) are major areas of study interest. Fourth Industrial Revolution solutions such as IoT, Blockchain, machine learning and others are often mentioned by authors of papers in database Scopus, highlighting how crucial the use of new technologies is to their SMS development, with an emphasis on Smart Grids (two biggest words in the Figure 2, the higher occurrence of a word, the larger the font; accordingly, as their size reduces, frequencies of occurrence will fall).

When we deepen the bibliometric analysis, we notice that the key word “Smart Grid” is dominated by “Smart Power Grids” (Figure 3). The studies of authors are clustered around the two strongest determinants of SES, which are: “Smart Power Grids” and “Smart Grid”. These two keywords (main research areas) must take into account the requirements of “Energy Efficiency” and “Energy Management” (neighboring clusters), and “Energy Storage”.

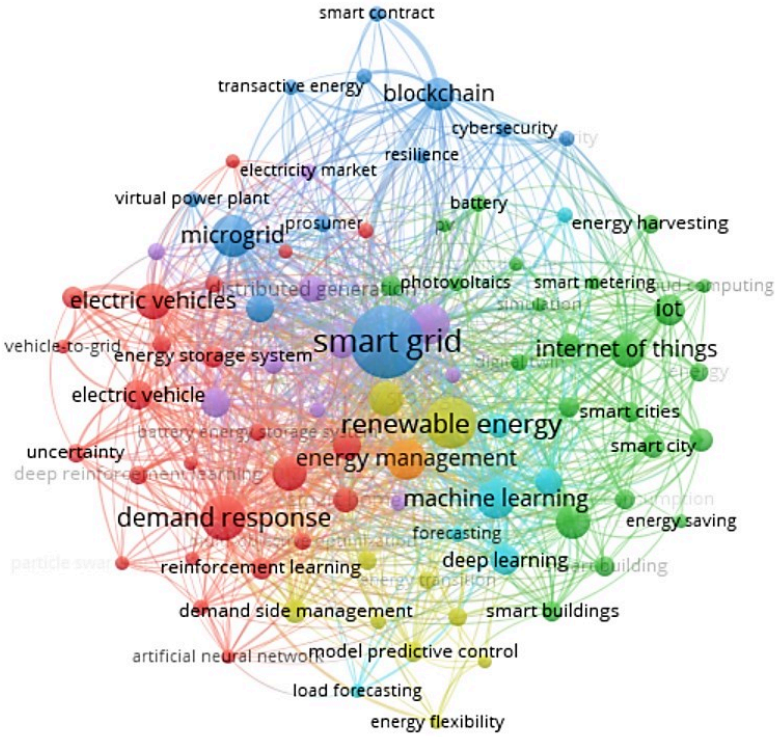

Figure 2. Word cloud for the co-occurrence - author key words (number of occurrence of keywords 50). Source: own elaboration based on bibliometric analysis of papers in Scopus database.

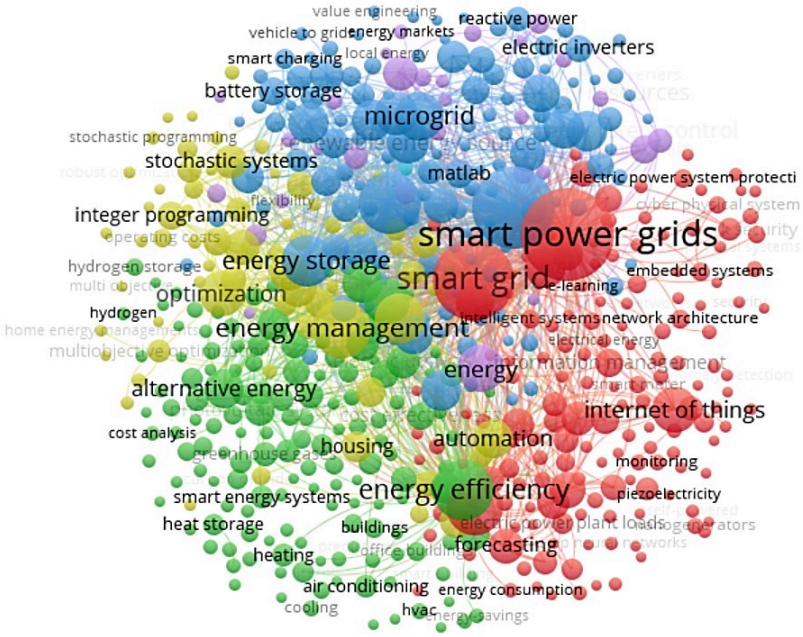

Figure 3. Word cloud for the co-occurrence - all key words (number of occurrence of keywords 50). Source: own elaboration based on bibliometric analysis of papers in Scopus database.

At this stage, in order to provide a more detailed insight into the analysis, a statistical examination was conducted using bag plots. A bag plot is a visualization technique that illustrates the distribution of data points across various categories or groups. In this context, the plot facilitates the exploration of the relationship between two key metrics: total link strength and occurrence. The keyword "smart power grids" appears most frequently, with 3572 occurrences and a total link strength of 24,102 (Table 1). This indicates significant attention from researchers towards this cluster in the context of smart energy systems development. Following this, "electric power transmission networks" is the second most frequently used keyword, appearing 2856 times with a total link strength of 19,454. This reflects the critical importance of transmission networks in the discourse on smart energy systems. The keyword "smart grid" ranks third, occurring 2689 times with a total link strength of 18,871. This further underscores the centrality of smart grid technology in contemporary research on energy systems. Other notable keywords include "renewable energy resources" (1629 occurrences, 12,804 total link strength), "energy management" (1427 occurrences, 11,719 total link strength) (Table 1). Figure 4 presents a bag plot illustrating the relationship between total link strength and occurrence for all keywords from bibliometric analysis. In the table 1 are selected keywords for it.

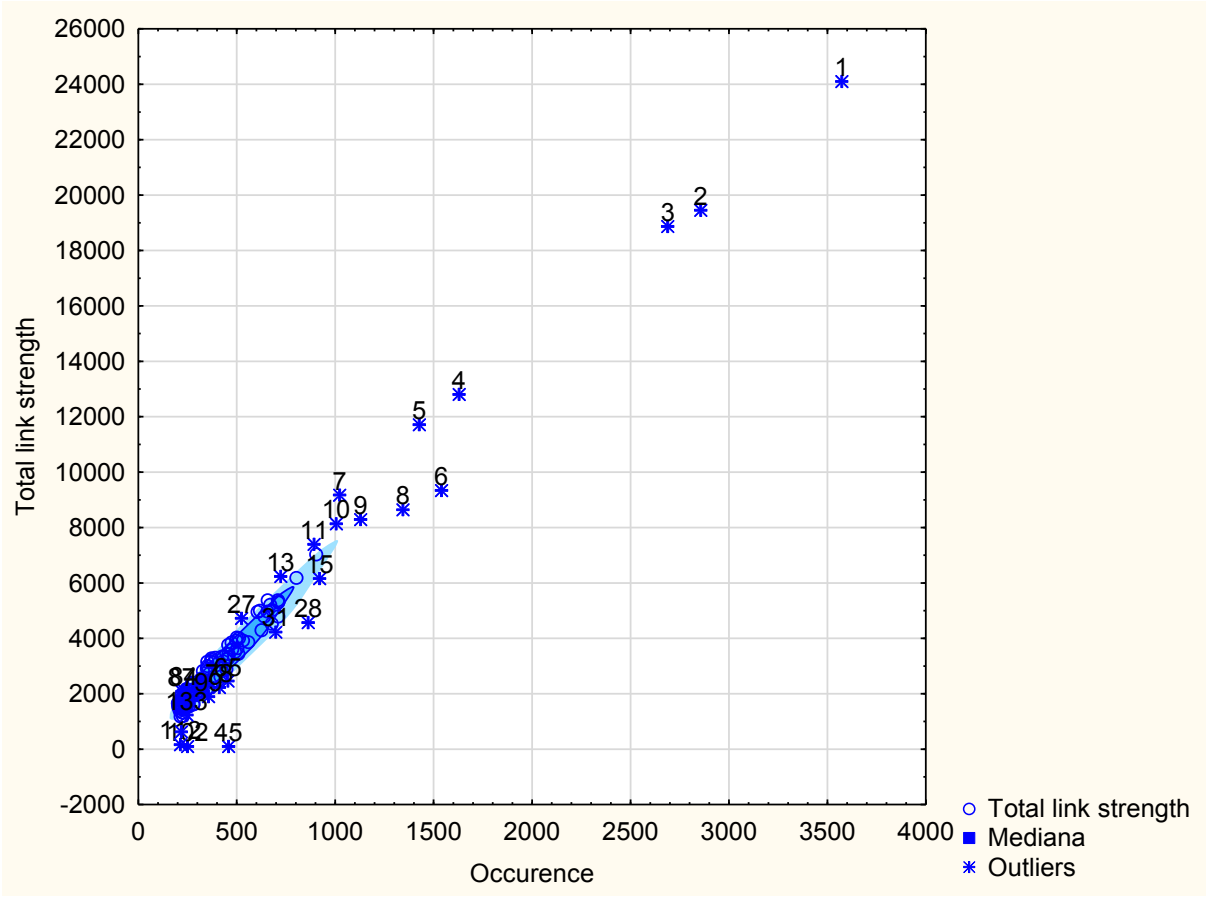

Figure 4. Bag plot – total link strength vs occurrence for all keywords.

Source: results of analysis by using computer programme (Statistica).

Table 1.
The of papers about Smart Energy System from Scopus according to keywords – selected keywords

Number	Key words	Occurrence	Total link strength
1	smart power grids	3572	24,102
2	electric power transmission networks	2856	194,54
3	smart grid	2689	18,871
4	renewable energy resources	1629	1,2804
5	energy management	1427	11,719
6	energy efficiency	1539	9337
7	energy management systems	1022	9174
8	energy utilization	1344	8643
9	energy storage	1129	8295
10	microgrids	1005	8133

By plotting total link strength against occurrence for all keywords, Figure 4 provides insights into the importance and prominence of various keywords within the dataset or context under study. The plot likely reveals patterns such as keywords that are highly linked but infrequently occurring, indicating their significance despite being less common. Conversely, keywords that are frequently occurring but have low link strength may suggest a lower level of importance within the dataset or context. In the bag plot depicting the relationship between occurrence and total link strength for keywords related to Smart Energy Systems, several patterns and insights can be discerned:

- High Occurrence, High Total Link Strength: Keywords situated in the upper-right quadrant of the plot, such as "smart power grids", "electric power transmission networks," and "smart grid," exhibit both high occurrence and high total link strength. For instance, "smart power grids" has an occurrence of 3572 and a total link strength of 24,102, indicating that it is not only frequently mentioned but also strongly linked across various sources. These keywords likely represent core concepts and focal points within the domain of Smart Energy Systems, attracting substantial attention and interest from researchers and practitioners alike.
- Low Occurrence, High Total Link Strength: Keywords positioned in the lower-right quadrant of the plot possess relatively low occurrence but high total link strength. Despite being less frequently mentioned, these keywords hold significant importance within specific niches or specialized areas of Smart Energy Systems. For instance, terms like "particle swarm optimization (PSO)" and "distributed power generation" may have limited occurrences in the dataset but are extensively linked, suggesting their relevance in specialized contexts or research domains.
- High Occurrence, Low Total Link Strength: Keywords falling in the upper-left quadrant exhibit high occurrence but low total link strength. These keywords are frequently mentioned but lack strong linkages across sources. For example, generic terms like "energy" or "power" are commonly referenced but may not be deeply interconnected or elaborately discussed in the dataset. Despite their frequent occurrence, these keywords

may represent broad concepts or overarching themes without specific associations or detailed discussions.

- Low Occurrence, Low Total Link Strength: Keywords located in the lower-left quadrant have both low occurrence and low total link strength. These keywords are infrequently mentioned and have limited linkages, indicating their marginal significance within the dataset. Terms like "air conditioning" and "heat storage" may fall into this category, representing relatively specialized topics that are not extensively discussed or linked within the context of Smart Energy Systems.

In focused researches, the most frequently occurring keyword is "smart grid". This keyword is appearing 1308 times with a total link strength of 1905, indicating its central role in this domain. Following closely are terms like "renewable energy" (645 occurrences, total link strength 913), "demand response" (520 occurrences, total link strength 888), "energy management" (422 occurrences, total link strength 724), and "microgrid" (442 occurrences, total link strength 684) (Table 2). In Figure 5 the data plot reveals distinct patterns based on the relationship between total link strength and occurrence for author keywords:

- High Occurrence, High Link Strength. This region of the plot contains keywords with both high occurrences and high total link strengths. Example keywords include "smart grid" (1308 occurrences, total link strength 1905), "renewable energy" (645 occurrences, total link strength 913), "demand response" (520 occurrences, total link strength 888), "energy management" (422 occurrences, total link strength 724), and "microgrid" (442 occurrences, total link strength 684).
- High Occurrence, Low Link Strength. Keywords in this area have high occurrences but relatively low total link strengths. Examples include "machine learning" (369 occurrences, total link strength 575), "electric vehicles" (332 occurrences, total link strength 481), "energy storage" (294 occurrences, total link strength 463), and "internet of things (IoT)" (302 occurrences, total link strength 419).
- Low Occurrence, High Link Strength. Keywords here have low occurrences but high total link strengths, indicating strong connections despite being mentioned less frequently. Examples include "blockchain" (282 occurrences, total link strength 440), "artificial intelligence" (181 occurrences, total link strength 341), and "deep learning" (227 occurrences, total link strength 327).

In the table 2 are selected keywords for it.

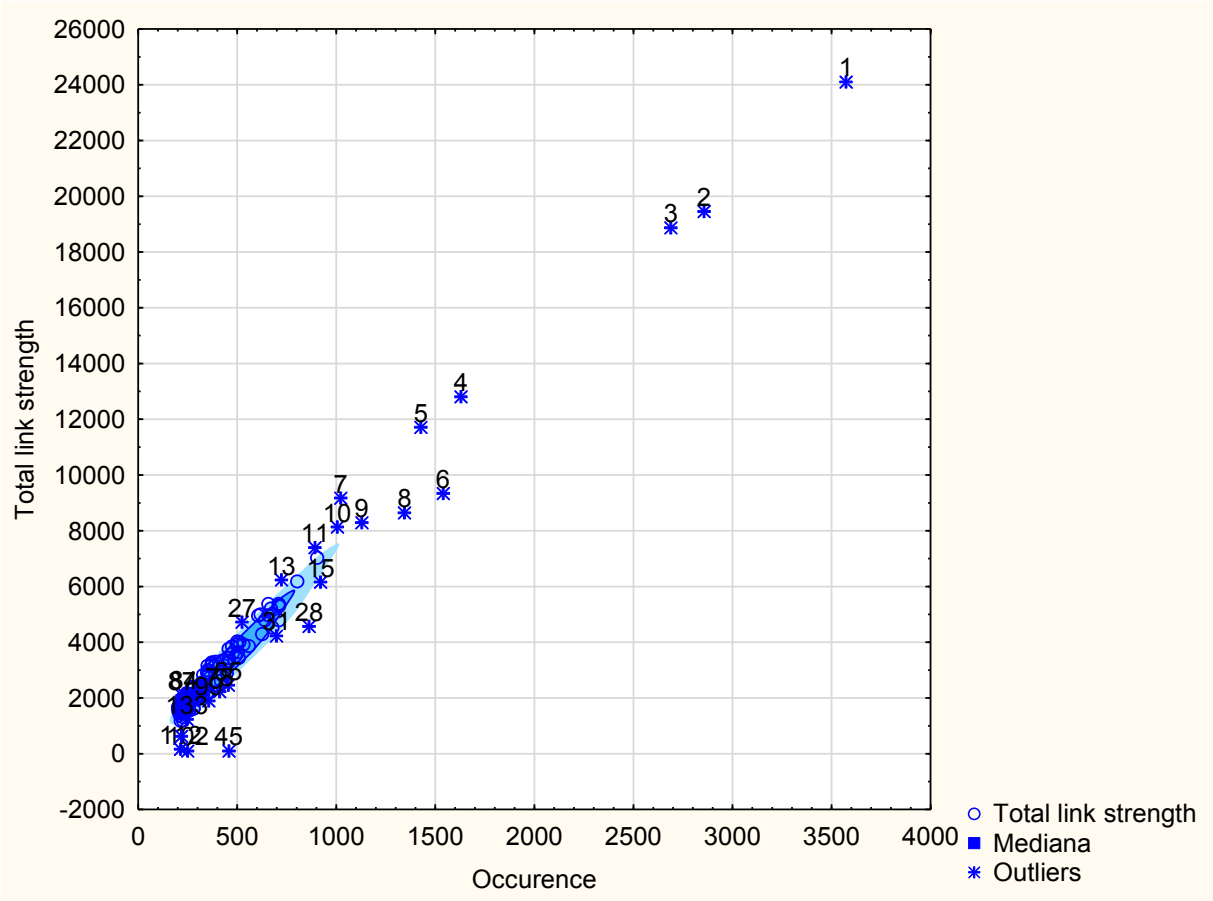

Figure 5. Bag plot – total link strength vs occurrence for author keywords.

Source: results of analysis by using computer programme (Statistica).

Table 2.

The of papers about Smart Energy System from Scopus according to keywords – selected keywords

Number	Key words	Occurrence	Total link strength
1	smart grid	1308	1905
2	renewable energy	645	913
3	demand response	520	888
4	energy management	422	724
5	microgrids	442	684
6	smart grids	425	581
7	machine learning	369	575
8	optimization	292	539
9	electric vehicles	332	481
10	energy storage	294	463

Empirical results indicate that "smart grid", "smart power grids", and "electric power transmission networks" are among the most popular topics in world research on Smart Energy Systems (SES) for 2020-2024. The outcome depends on the theoretical basis advanced by Lund et al. (2012, 2017), who emphasized the transition from a grid-constrained electricity paradigm to an integrated smart energy system approach. They propose that SES would have to put some areas—electricity, heat, transport—under one roof through smart infrastructure and information technology to achieve systemic optimisation. Bibri et al. (2017) also agreed on such

an integrated concept by referring to coordination across sectors, digital management systems, and green city planning while formulating next-generation smart cities and energy systems.

The most evident conclusion of statistical findings is the frequency and intensity of co-occurrence of terms like "energy efficiency", "energy management", and "renewable energy resources". The trends reinforce earlier research findings of Dincer and Acar (2017), who highlighted the top priority for smart energy systems to meet sustainability objectives should be efficient use of energy and renewables integration. This corresponds to Xu et al. (2020) emphasis on SES system design with intelligent control, automation, and performance optimization. Furthermore, ubiquitous presence of "microgrids" as a new development mirrors the outcome of Mbungu et al. (2020), who asserted that decentralized smart-controlled microgrid systems offer tremendous potential to improve reliability, resilience, and cost-effectiveness in small-scale energy systems.

Categorization of emergent technologies as "blockchain", "IoT", "machine learning", and "artificial intelligence" outlier but increasingly forceful terms defines the trend towards digitalized, autonomous, and decentralized SES designs. The same has been attested by Erturk (2019), who studied the use of blockchain for safe peer-to-peer trading and energy data exchange, and Khatua et al. (2019), who quoted IoT and AI as enablers of system-wide responsiveness and automation. Simultaneously the demand for advanced optimization techniques in system and control design, as referenced by Fadaee and Radzi (2012) and Suganthi et al. (2015), is in the same ratio the primary frequency of "optimization" as the search term in the literature. Overall, the findings indicate a shift in paradigm in SES research towards the integration of Fourth Industrial Revolution uses of technology for adaptive and real-time energy management in various applications and scales.

5. Conclusion

From 2020 to 2024, global research activity in Smart Energy Systems (SES) has been marked by staccato convergence of green needs and technology advancement, as evidenced in the dominant science trends and theme concentrations in the bibliometric overview. The most frequently used terms, i.e., “smart grid”, "smart power grids", "electric power transmission", "renewable energy resources", "energy management", and "energy efficiency", suggest caution with system optimization, integration of renewable energy, and digital control technology advancement (RQ1 and RQ2). In a broader sense, the augmented usage of the terms "Internet of Things (IoT)", "optimization", and "blockchain" is reflective of the augmented utilization of data-driven, networked infrastructure in advancing energy system responsiveness, flexibility, and sustainability. Thematic co-occurrence clustering and keyword network visualization indicate a multidisciplinary technology space with clusters in smart grid technology, renewable

integration, digital management systems, and automation. This aligns with the growing maturity of the field and its overlap with global goals of decarbonization, decentralized power generation, and smart system integration, and places SES research at the nexus of management, environmental policy, and information science.

The emergent topics in SES literature and outlying words during 2020-2024 represent a strategic agenda of digitalization, decentralization, and cross-sectoral integration of energy systems. “IoT”, "Blockchain", "machine learning", "deep learning", "artificial intelligence" are the most emergent new topics in the SES research could focus on intelligent automation, decentralized transactional systems, and other energy carriers capable of enhancing system resilience and sustainability.

Limitation of our analysis: One of the principal disadvantages of this research is the use of the Scopus database exclusively, although broad, and hence potentially excluding relevant publications in other indexing databases that could reduce bibliometric analysis coverage. Furthermore, keyword-based mapping and co-occurrence network focus might ignore more sophisticated conceptual development deserving detailed qualitative examination beyond frequency statistics' capabilities.

The subsequent analyses are suggested to be carried out through multi-databases, i.e., Web of Science and IEEE Xplore, in order to make bibliometric evaluation encompass a wide range of scholarly output. In addition, combining bibliometric analysis with qualitative content analysis or case studies would likely yield even richer contextual intelligence regarding driver forces and policy pressures to guide Smart Energy System design.

References

1. Aghamolaei, R., Shamsi, M.-H., Tahsildoost, M., O'Donnell, J. (2018). Review of district-scale energy performance analysis: Outlooks towards holistic urban frameworks. Sustainable Cities and Society.
2. Ali, M., Prakash, K., Hossain, M.A., Pota, H.R. (2021). Intelligent energy management: Evolving developments, current challenges, and research directions for a sustainable future. *Journal of Cleaner Production, 314*, 127904. https://doi.org/10.1016/j.jclepro.2021.127904
3. Anjana, K.R., Shaji, R.S. (2017). A review on the features and technologies for energy efficiency of smart grid. *International Journal of Energy Research*. https://doi.org/10.1002/er.3852
4. Bahramara, S., Moghaddam, M.P., Haghifam, M.R. (2016). Optimal planning of hybrid renewable energy systems using HOMER: A review. *Renewable and Sustainable Energy Reviews, 62*, 609-620. https://doi.org/10.1016/j.rser.2016.05.039

5. Bibri, S.E. et al. (2017). Smart sustainable cities of the future: An extensive interdisciplinary literature review. *Sustainable Cities and Society*.
6. Bossel, U. (2005, September). *On the way to a sustainable energy future*. 27th International Telecommunications Conference (INTELEC), 659-668.
7. Crossley, P., Beviz, A. (2010). Smart energy systems: Transitioning renewables onto the grid. *Renewable Energy Focus, 11*, 54-59. https://doi.org/10.1016/s1755-0084(10)70118-6
8. Dincer, I., Acar, C. (2017). Smart energy systems for a sustainable future. *Applied Energy, 194*, 225-235. https://doi.org/10.1016/j.apenergy.2016.12.058.
9. Edgar, T.F., Pistikopoulos, E.N. (2018). Smart manufacturing and energy systems. *Computers & Chemical Engineering, 114*, 130-144. https://doi.org/10.1016/ j.compchemeng.2017.10.027
10. Elliston, B., Diesendorf, M., & MacGill, I. (2012). Simulations of scenarios with 100% renewable electricity in the Australian National Electricity Market. *Energy Policy, 45*, 606–613. https://doi.org/10.1016/j.enpol.2012.03.011.
11. Erturk, E. (2019). Benefits and risks of using blockchain in smart energy: A literature review. *Contemporary Management Research, 15(3*), 205-225. https://doi.org/10.7903/cmr.19650
12. Fadaee, M., Radzi, M. (2012). Multi-objective optimization of a stand-alone hybrid renewable energy system by using evolutionary algorithms: A review. *Renewable and Sustainable Energy Reviews, 16*, 3364-3369. https://doi.org/10.1016/j.rser.2012.02.071.
13. Gajdzik, B., Wolniak, R., Nagaj, R., Žuromskaitė-Nagaj, B., Grebski, W. (2025) Energy Waste as a Side-Effect of Photovoltaic Development: Net Impact of Photovoltaics on CO2 Emissions in European Union Countries. *Energies, 18(1),* 78. https://doi.org/10.3390/en18010078.
14. Gajdzik, B., Jaciow, M., Wolniak, R., Wolny, R., Grebski, W. (2024a). Diagnosis of the development of energy cooperatives in Poland - a case study of a renewable energy cooperative in the Upper Silesian region. *Energies, 17(3), 647*, 1-27. https://doi.org/10.3390/en17030647.
15. Gajdzik, B., Jaciow, M., Wolniak, R., Wolny, R., Grebski, W.W. (2023b). Assessment of energy and heat consumption trends and forecasting in the small consumer sector in Poland based on historical data. *Resources, 12, 111*. https://doi.org/10.3390/resources12090111
16. Gajdzik, B., Nagaj, R., Wolniak, R., Bałaga, D., Žuromskaitė, E., Grebski, W.W. (2024b). Renewable energy share in European industry: Analysis and extrapolation of trends in EU countries. *Energies, 17(2476).* https://doi.org/10.3390/en17112476.
17. Gajdzik, B., Nagaj, R., Wolniak, R., Bałaga, D., Žuromskaitė, E., Grebski, W.W. (2024b). Renewable energy share in European industry: Analysis and extrapolation of trends in EU countries. *Energies, 17(2476).* https://doi.org/10.3390/en17112476.

18. Gajdzik, B., Sroka, W., Vveinhardt, J. (2021). Energy intensity of steel manufactured utilising EAF technology as a function of investments made: The case of the steel industry in Poland. *Energies, 14, 5152*. https://doi.org/10.3390/en14165152.
19. Gajdzik, B., Wolniak, R., Nagaj, R., Grebski, W.W., Romanyshyn, T. (2023d). Barriers to renewable energy source (RES) installations as determinants of energy consumption in EU countries. *Energies, 16, 7364*. https://doi.org/10.3390/en16217364.
20. Ionescu, R.-V., Zlati, M.L., Antohi, V.-M., Susanu, I.O., Cristache, N. (2022). A new approach on renewable energy as a support for regional economic development among the European Union. *Technological Forecasting and Social Change, 184*, 121998. https://doi.org/10.1016/j.techfore.2022.121998.
21. Khalid, M. (2024). Smart grids and renewable energy systems: Perspectives and grid integration challenges. *Energy Strategy Reviews, 51, 101299*. https://doi.org/10.1016/j.esr.2024.101299.
22. Khatua, P.K., Ramachandaramurthy, V.K., Kasinathan, P., Yong, J.Y., Pasupuleti, J., Rajagopalan, A. (2019). Application and assessment of Internet of Things toward the sustainability of energy systems: Challenges and issues. *Sustainable Cities and Society*. https://doi.org/10.1016/j.scs.2019.101957.
23. Krajačić, G., Duić, N., Da Carvalho, M.G. (2011). How to achieve a 100% RES electricity supply for Portugal? *Applied Energy, 88*, 508-517. https://doi.org/10.1016/j.apenergy. 2010.09.006
24. Kvasničková Stanislavská, L., Pilař, L., Vogli, X., Hlavsa, T., Kuralová, K., Feenstra, A., Pilařová, L., Hartman, R., Rosak-Szyrocka, J. (2023). Global analysis of Twitter communication in corporate social responsibility area: Sustainability, climate change, and waste management. *PeerJ Computer Science, 9, e1390*. https://doi.org/10.7717/peerj-cs.1390.
25. Lund, H. (2014). *Renewable energy systems: A smart energy systems approach to the choice and modeling of 100% renewable solutions* (2nd ed.). Academic Press; Elsevier Science & Technology Books. ISBN 9780124095953.
26. Lund, H., Andersen, A.N., Østergaard, P.A., Mathiesen, B.V., Connolly, D. (2012). From electricity smart grids to smart energy systems – A market operation-based approach and understanding. *Energy, 42*, 96-102. https://doi.org/10.1016/j.energy.2012.04.003.
27. Lund, H., Østergaard, P.A., Connolly, D., Mathiesen, B.V. (2017). Smart energy and smart energy systems. *Energy, 137*, 556-565. https://doi.org/10.1016/j.energy.2017.05.123.
28. Mason, I.G., Page, S.C., Williamson, A.G. (2010). A 100% renewable electricity generation system for New Zealand utilising hydro, wind, geothermal and biomass resources. *Energy Policy, 38*, 3973-3984. https://doi.org/10.1016/j.enpol.2010.03.022.
29. Mbungu, N.T., Bansal, R.C., Naidoo, R.M., Bettayeb, M., Siti, M.W., Bipath, M. (2020). A dynamic energy management system using smart metering. *Applied Energy, 280, 115990*. https://doi.org/10.1016/j.apenergy.2020.115990.

30. Md Shopan Ali, Anik Sharma, Tamal Ahammed Joy, Md Abdul Halim. (2024). A comprehensive review of integrated energy management for future smart energy system. *Control Systems and Optimization Letters, 2,* 43-51. https://doi.org/10.59247/csol.v2i1.77.
31. Mohammadi, M., Noorollahi, Y., Mohammadi-Ivatloo, B. (2018). An introduction to smart energy systems and definition of smart energy hubs. In: B. Mohammadi-Ivatloo, F. Jabari (eds.), *Operation, planning, and analysis of energy storage systems in smart energy hubs* (pp. 1-22). Springer. https://link.springer.com/book/10.1007/978-3-319-75097-2
32. Nagaj, R., Gajdzik, B., Wolniak, R., Grebski, W.W. (2024). The Impact of Deep Decarbonization Policy on the Level of Greenhouse Gas Emissions in the European Union. *Energies, 17, 1245*.
33. Østergaard, P.A. (2015). Reviewing EnergyPLAN simulations and performance indicator applications in EnergyPLAN simulations. *Applied Energy, 154*, 921-933. https://doi.org/10.1016/j.apenergy.2015.05.086..
34. Pan, M., Zhao, X., Lv, K., Rosak-Szyrocka, J., Mentel, G., Truskolaski, T. (2023). Internet development and carbon emission-reduction in the era of digitalization: Where will resource-based cities go? *Resources Policy, 81,* 103345. https://doi.org/10.1016/j.resourpol. 2023.103345.
35. Razmjoo, A., Mirjalili, S., Aliehyaei, M., Østergaard, P.A., Ahmadi, A., Majidi Nezhad, M. (2022). Development of smart energy systems for communities: Technologies, policies and applications. *Energy, 248, 123540*. https://doi.org/10.1016/j.energy.2022.123540.
36. Rosokhata, A., Minchenko, M., Khomenko, L., Chygryn, O. (2021). Renewable energy: A bibliometric analysis. *E3S Web of Conferences, 250,* 3002. https://doi.org/10.1051/e3sconf/202125003002
37. Ryu, H., Dorjragchaa, S., Kim, Y., Kim, K. (2014). Electricity-generation mix considering energy security and carbon emission mitigation: Case of Korea and Mongolia. *Energy, 64*, 1071-1079. https://doi.org/10.1016/j.energy.2013.10.089.
38. Suganthi, L., Iniyan, S., Samuel, A.A. (2015). Applications of fuzzy logic in renewable energy systems – A review. *Renewable and Sustainable Energy Reviews, 48*, 585-607. https://doi.org/10.1016/j.rser.2015.04.037.
39. Wang, C., Lv, T., Deng, X. (2020). Bibliometric and visualized analysis of China's smart grid research 2008-2018. *Frontiers in Research Metrics and Analytics, 5, 551147*. https://doi.org/10.3389/frma.2020.551147.
40. Wang, Q., Huang, R., Li, R. (2022). Towards smart energy systems – A survey about the impact of COVID-19 pandemic on renewable energy research. *Energy Strategy Reviews, 41, 100845*. https://doi.org/10.1016/j.esr.2022.100845
41. Wolniak, R., Saniuk, S., Grabowska, S., Gajdzik, B. (2020). Identification of energy efficiency trends in the context of the development of Industry 4.0 using the Polish steel sector as an example. *Energies, 13(11), 2867*. https://doi.org/10.3390/en13112867.

42. Xu, Y., Yan, C., Liu, H., Wang, J., Yang, Z., Jiang, Y. (2020). Smart energy systems: A critical review on design and operation optimization. *Sustainable Cities and Society, 62, 102369*. https://doi.org/10.1016/j.scs.2020.102369.
43. Yang, X., Song, Y., Wang, G., Wang, W. (2010). A comprehensive review on the development of sustainable energy strategy and implementation in China. *IEEE Transactions on Sustainable Energy, 1(2),* 57-65. https://doi.org/10.1109/TSTE.2010.2051464.
44. Zhang, J., Quoquab, F., Mohammad, J. (2024). Plastic and sustainability: A bibliometric analysis using VOSviewer and CiteSpace. *Arab Gulf Journal of Scientific Research, 42,* 44-67. https://doi.org/10.1108/AGJSR-10-2022-0225
45. Zheng, Z., Shafique, M., Luo, X., Wang, S. (2024). A systematic review towards integrative energy management of smart grids and urban energy systems. *Renewable and Sustainable Energy Reviews, 189, 114023*. https://doi.org/10.1016/j.rser.2023.114023.
46. Zhou, Ch., Richardson-Barlow, C., Fan, L., Cai, H., Zhang, W., Zhang, Z. (2025). Towards organic collaborative governance for a more sustainable environment: Evolutionary game analysis within the policy implementation of China's net-zero emissions goals. *Journal of Environmental Management, 373, 123765*, DOI: 10.1016/j.jenvman.2024.123765.
47. Zhu, H., Goh, H.H., Zhang, D., Ahmad, T., Liu, H., Wang, S., Li, S., Liu, T., Dai, H., Wu, T. (2022). Key technologies for smart energy systems: Recent developments, challenges, and research opportunities in the context of carbon neutrality. *Journal of Cleaner Production, 331, 129809*. https://doi.org/10.1016/j.jclepro.2021.129809.

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APPLICATION OF DIGITAL TWIN IN ENSURING CYBER-SECURITY IN MANUFACTURING PROCESSES MANAGEMENT

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Purpose: The objective of the paper is twofold: firstly, to analyze the applications of Digital Twin (DT) technology in ensuring cybersecurity in manufacturing processes; and secondly, to identify key thematic areas, research gaps, and potential practical applications.
Design/methodology/approach: The research was conducted based on a systematic literature review, using bibliometric analysis and advanced data analysis tools such as VOSviewer and Latent Dirichlet Allocation (LDA).
Findings: The literature analysis revealed that current studies focus on the analysis of DT use in risk management and security testing without interference in real manufacturing systems. DT facilitates the emulation of a variety of threat scenarios, the evaluation of the efficacy of implemented security measures, and the optimization of preventive strategies. However, the analysis also identified significant research gaps, including the lack of unified implementation methodologies and insufficient exploration of the impacts of DT deployment in cybersecurity at operational and strategic levels.
Practical implications: The implementation of DT has the potential to enhance cybersecurity risk management in manufacturing enterprises by facilitating earlier threat detection, minimizing potential losses, and expediting incident response times. DT provides enterprises with tools for continuous monitoring of manufacturing processes, enabling proactive threat management and increasing system resilience.
Originality/value: The study proposes an interdisciplinary approach, with a view to identifying a research niche related to the integration of DT with other information technologies. Furthermore, it outlines directions for developing methodologies and standards for DT implementation in manufacturing processes, with a view to ensuring their cybersecurity.
Keywords: digital twin, cybersecurity, risk management, manufacturing processes, process resilience.
Paper type: Research paper.

1. Introduction

In the contemporary digital landscape, manufacturing processes are becoming increasingly susceptible to a range of threats that have the potential to disrupt their continuity. Among the most serious of these are cyber-attacks such as ransomware, which have the potential to block access to critical control systems and force production shutdowns. Another significant threat is the loss of technological data or know-how, which can potentially result in the loss of competitive advantage. Additionally, the frequency of phishing attacks targeting employees operating production systems, as well as manipulations of data transmitted between devices, for example in the power sector, is increasing. The integration of information technology systems and industrial automation has led to an increased risk of exploitation due to vulnerabilities in software and IoT devices, which could be used for sabotage or industrial espionage. Consequently, the implementation of advanced cyber protection measures, in conjunction with the continuous training of employees in digital security, is imperative.

The present paper explores the potential of Digital Twin (DT) technology in ensuring the cybersecurity of manufacturing processes. This subject is infrequently addressed in the extant literature; however, it is of considerable significance for manufacturing enterprises. The growing interest in the DT concept is leading to the implementation of its individual components (the digital model or digital shadow) in enterprises. However, there is still a paucity of established methodologies for implementation. Enterprises must be willing to make significant investments of both time and financial resources, in addition to implementing comprehensive risk management strategies. As the DT concept evolves, the associated threats have also increased, particularly in the digital domain, where DT, in addition to internal threats, can itself become a subject of research regarding the threats it poses to the mirrored physical production system. Despite the paucity of literature in this area, it is acknowledged that there are opportunities for enterprises to utilize already implemented tools and technologies.

As a result, most research in the area of DT focuses on its proper implementation in an enterprise, or on the capabilities it offers organizations for making predictions, analyzing data or controlling production processes. However, research into additional supporting applications of DT in the enterprise beyond its core functionality is lacking. One such application could be using DT to ensure the safety of production processes. This can be achieved by collecting and processing real-time data on current process flows, performing simulations of future events, generating alerts and warnings, and proactively preventing undesirable conditions.

In this context, the paper aims to analyze the application of DT technology in ensuring cybersecurity for manufacturing processes. The discussion focuses on the identification of thematic areas and research gaps, and the determination of practical applications of DT for risk management. It also attempts to set directions for future research and outline support for manufacturing enterprises in implementing effective cybersecurity strategies.

Chapter 2 delineates the research methodology and assumptions that underpinned the literature review. Chapter 3 presents the research findings, including an analysis of publications using the Global Citation Score (GCS), VOSviewer and the Latent Dirichlet Allocation (LDA) method. The fourth chapter contains a discussion of the findings and responses to research questions. The paper concludes with a summary of the research and indicates directions for future work.

2. Materials and Methods

2.1. Research methodology

The research employed a six-step research procedure. Initially, the research problem was defined, followed by a systematic literature review. The study was conducted using selected bibliometric databases (from two data-base: Web of Science Core Collection and Scopus) with defined keywords. The research focused on identifying publications dealing with ensuring cybersecurity in manufacturing processes. Preliminary research conducted by the authors revealed a small number of publications on this subject. Publications were selected and analyzed using citation indices. Literature review support tools such as VOSviewer and the LDA method were utilized. These activities facilitated the identification of key publications concerning the use of DT technology for ensuring cybersecurity in manufacturing processes. Subsequently, results obtained from various stages of literature analysis were compared. Major thematic areas addressed in the literature concerning cybersecurity challenges in manufacturing enterprises were identified. The outcomes enabled the formulation of answers to the posed research questions. The final step involved outlining recommendations and directions for future research. The applied research methodology was presented in Figure 1.

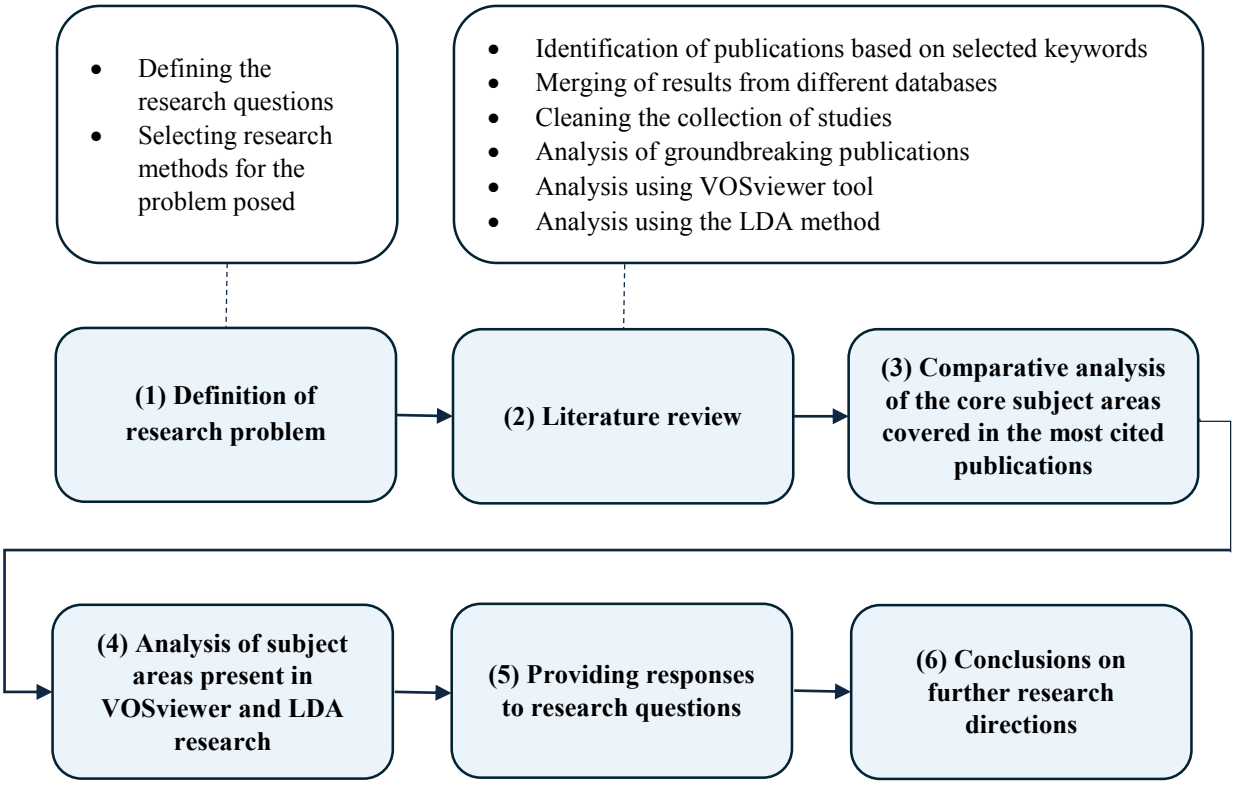

Figure 1. Research methodology applied.

Source: own study.

As part of the study four research questions were formulated, as shown in Table 1.

Table 1.
The defined research questions

Research question	Description
RQ1	What fields in the application of DTs in the area of cyber security are studied in the literature?
RQ2	Are DTs applied in the area of risk management in manufacturing processes?
RQ3	What is the nature of DT application in the area of cybersecurity assurance?
RQ4	What are the opportunities and threats facing the implementation of DT in the area of cybersecurity?

Source: own study.

Answers to the questions posed will be sought in the literature. Furthermore, the text will outline new subject areas and potential applications of DT that are emerging in research.

2.2. Systematic literature review – assumptions

A systematic literature review was selected due to its rigorous procedures for searching and selecting papers, making it a tool capable of providing reproducible research results based on defined parameters (Snyder, 2019). Exploration of existing literature was based on identifying available studies through a defined set of keywords. The selection of papers for bibliometric analysis focused on constructing queries encompassing various terms, synonyms,

and abbreviations related to DT technology, cybersecurity, manufacturing processes, and their mutual interactions.

The literature search was conducted using two databases: Web of Science Core Collection (WoSCC) and Scopus. These databases were chosen as they are leading platforms with significant scientific impact (Visser et al., 2021). Keyword selection was guided by a scoping study framework (Arksey, O'Malley, 2005). Scoping studies aim to map literature related to a specific topic or research area to support the identification of key concepts, research gaps, or evidence. Keywords and search strings were adjusted to include a broad range of publications describing the relationships between the application of DT technology and cybersecurity in manufacturing processes.

Based on this approach, queries were formulated to search titles, keywords, and abstracts with a defined time limit. The search focused on publications issued after 2002, marking the first appearance of the concept of conducting simulations in cloned environments in the digital world, presented by Michael Grieves at the University of Michigan (Grieves, Vickers, 2017). No disciplinary restrictions were applied due to the interdisciplinary nature of the topic spanning engineering, computer science, and management. Other exclusion criteria were not used, allowing consideration of all document types. Queries were entered into Scopus (Eq. 1) and WoSCC (Eq. 2) databases on February 3, 2025, and are presented in Table 2.

Table 2.
List of queries that have been entered into databases

Equation	Inquiry formula
Equation #1	TITLE-ABS-KEY (("Digital twin") AND ("production process" OR "manufacturing process" OR "production" OR "manufacturing") AND ("cybersecurity" OR "data security" OR "information security" OR "IT security" OR "network security" OR "data safety" OR "information safety" OR "IT safety" OR "network safety")) AND PUBYEAR > 2001 AND PUBYEAR < 2026
Equation #2	(TS=("Digital twin")) AND (TS=("production process") OR TS=("manufacturing process") OR TS=(production) OR TS=(manufacturing)) AND (TS=(cybersecurity) OR TS=("data security") OR TS=("information security") OR TS=("IT security") OR TS=("network security") OR TS=("data safety") OR TS=("information safety") OR TS=("IT safety") OR TS=("network safety"))

Source: own study.

The selection of keywords was conducted in accordance with the objective of the paper, namely the broad identification of studies related to the application of DT technology for ensuring cybersecurity in manufacturing processes. The query to the SCOPUS database (Eq. 1) yielded 248 papers, while the query to the WoS CC database (Eq. 2) returned 53 publications. Subsequent to this, both datasets were combined with a view to eliminating duplicates. The papers were then compared based on their DOI numbers and titles, resulting in the identification and removal of 45 duplicate works.

Subsequently, the entire set of 256 publications underwent a preliminary review, involving an examination of topics and abstracts. The objective of this stage was to exclude papers that were not related to the subject under analysis. This process was conducted meticulously,

and no studies deviating from the intended scope of the research were identified. A systematic analysis of the publications was then conducted.

In the first stage, the GCS was determined to identify the most frequently cited publications. The GCS index has been demonstrated to facilitate the identification of studies utilized by other authors to support research in analogous topics (Knoke, Yang, 2008). Citations of the considered publications were counted, even if they originated from papers not identified or selected for this study. The final stage of the study involved the ranking of papers according to the number of citations divided by the number of years since publication. This approach enabled the identification of studies that potentially possessed a low GCS but recently gained considerable interest.

In the subsequent stage of the research, a co-occurrence network analysis of keywords was conducted using the VOSviewer software. Co-occurrence analysis has been demonstrated to be applicable to keywords, authors, classifications of works, and other descriptive characteristics of publications (Morris, 2000). There are three primary types of co-occurrence analysis: (1) co-occurrence of authors (co-operation analysis), (2) co-occurrence of authors and keywords (coupling analysis), and (3) co-occurrence of keywords (co-word analysis) (Lou, Qiu, 2014). The present paper employed keyword co-occurrence analysis, with a particular focus on keywords provided by authors and indexed in bibliometric databases. This approach has been demonstrated to facilitate the identification of the structural intricacies within the research domain under scrutiny, in addition to its potential implications for the broader discipline. The application of keyword co-occurrence generates a map in which the size of each node represents the frequency of a keyword, and lines indicate relationships between respective keywords (Lis, 2018). The identified network of relationships segments the analyzed outputs into thematic clusters, facilitating the identification of major research topics and knowledge gaps.

Furthermore, a citation map was utilized to perform a network analysis of the selected studies. A citation network comprises nodes representing publications and links indicating citations among them. This approach facilitates the observation of knowledge flow and citation relationships between works. Consequently, this approach enables the identification of clusters (smaller networks) that include papers with at least one connection to another paper within the cluster (Knoke, Yang, 2008).

In the third stage, the content analysis of the identified studies was deepened through the implementation of research utilizing the LDA method. LDA is a thematic modelling technique that is frequently employed in scientific research to identify key research subjects or trends in domains such as medical sciences, software engineering, political sciences, geography, or corporate architecture (Horn et al., 2021). In contradistinction to the VOSviewer tool, LDA is capable of analyzing any text strings, thereby facilitating a more profound comprehension of the content of publications than is possible through keyword-only analyses. The LDA method was first introduced by Blei, Ng, and Jordan (Blei et al., 2003). The thematic relationship model

created through LDA represents thematic areas through word probabilities, with the most probable words in each thematic area serving as representations of that area's characteristics or determinants (Chuang et al., 2012). To facilitate interpretation, Chuang, Manning, and Heer introduced a visualization and interpretation method for thematic areas, which later inspired Sievert and Shirley to develop LDAvis—a method for interpreting LDA results (Sievert, Shirley, 2014).

The input data for the LDA analysis comprised a dataset containing abstracts of all publications that had been classified for the study. The analysis employed the PyCaret library, implementing the LDA algorithm supported by the LDAvis visualization technique (Moez, 2009). Initially, the model was configured using the most common insignificant words (e.g., use, paper, research, start, etc.) as so-called stop-words (Yeung, 2018). Subsequently, the obtained results were evaluated, and coherence values were calculated to determine the number of thematic areas.

3. Results

A total of 256 studies were identified, addressing the topic of using the DT in the area of cyber-security of manufacturing processes. The selected publications were then subjected to further investigation in three areas: (1) to determine the hierarchy and scientific popularity of the publications, (2) to conduct an analysis of the topics covered using the VOSviewer tool, and (3) to conduct an analysis of the research topics covered using the LDA method. The results of this study are presented below.

3.1. Determination of GCS index (Global Citation Score)

The number of papers obtained (256) in the context of the total number of papers discussing the topics of the DT (28,630 papers in the SCOPUS database and 15,701 in the WoS CC database), cyber-security (41,861 papers in the SCOPUS database and 23,960 in the WoS CC database) and manufacturing processes (2,176,792 in the SCOPUS database and 987,692 in the WoS CC database) indicates the niche nature of this issue. The subjects of the DT, cybersecurity and manufacturing processes are the focus of extensive discussion in the existing literature. However, there is a paucity of cross-sectional studies that address the interdependence of these topics. The subject has been of scholarly discussion, but the relatively low percentage of papers suggests the existence of a research gap.

Table 3 presents a comprehensive overview of the ten most-cited papers, meticulously ranked according to their GCS, with the years since publication taken into account to provide a more nuanced perspective on the evolution of research in this field.

Table 3.
Ranking of the 10 most cited papers by year

Paper	Number of citations	Number of citations by year
(Mihai et al., 2022)	396	99
(Alcaraz, Lopez, 2022)	148	37
(Cai et al., 2017)	304	34
(Qian et al., 2022)	92	23
(Mullet et al., 2021)	84	17
(Bhatt et al., 2021)	75	15
(Eckhart, Ekelhart, 2019)	104	15
(Jbair et al., 2022)	58	15
(Thakur et al., 2023)	43	14
(Holmes et al., 2021)	68	14

Source: own study.

3.2. Analysis of key publications based on GCS index

The most prominent study (Mihai et al., 2022) has been shown to clearly surpass other publications and can be regarded as establishing the direction for scientific discussion in this area. The authors of the study emphasized that DT is a technology generating high expectations, with the potential to stimulate significant changes in manufacturing processes and society at large. DT offers a platform for testing and analyzing complex systems, something challenging to achieve through traditional simulations. However, the development of DT faces numerous challenges, including the complexity of effective communication and data collection, the unavailability of data for training machine learning models, insufficient computational power to handle high-fidelity twins, a substantial need for interdisciplinary collaboration, and the absence of standardized development methodologies and validation measures.

Alcaraz and Lopez (2022) emphasize the mounting significance of Industry 4.0 in the value chain, through the modernization, digitization, and optimization of production and distribution processes. The authors further note that the deployment of DT is based on integrating technologies such as cyber-physical systems, Industrial Internet of Things (IIoT), edge computing, virtualization infrastructure, artificial intelligence, and big data. However, the integration and hidden interaction with physical counterparts generate numerous security threats, which remain insufficiently studied.

In the study by Cai et al. (2017), the integration of sensor data is explored with a view to creating DTs for virtual machine tools in the context of cyber-physical manufacturing. These virtual tools have the capacity to simulate machine tool capabilities in a safe and cost-effective manner. In the event of a physical machine tool malfunctioning or operating in an incorrect manner, engineers are able to refer to the digital traces provided by the DT for diagnostic purposes. Such data can also enhance resilience against failures in cyber-physical production.

As illustrated in Table 1, other studies have received an average of fewer than 25 citations per year, yet the majority were published after 2020 and have garnered at least 14 citations annually, signifying notable researcher interest in DT for cybersecurity in manufacturing.

Qian et al. (2022) observe that direct manipulation or updates of actual manufacturing systems carry risks of adverse situations. The creation of DTs has been demonstrated to enhance the safety of manufacturing processes. The design of DTs for manufacturing systems must take into account numerous real-world parameters, including delays, reliability, safety, scalability, security, and privacy.

Mullet et al. (2021) provide a comprehensive review of digital threats to factories operating within the Industry 4.0 paradigm. Despite the extensive literature on cybersecurity, many factory managers have only recently recognized its impact on business continuity. The authors have selected and reviewed a limited number of recent papers, highlighting operational goals, adopted technical solutions, and evaluations.

Bhatt et al. (2021) emphasize that access control is a critical security mechanism for securing IoT ecosystems, incorporating cloud and edge computing services alongside smart devices.

Eckhart and Ekelhart (2019) posit that the implementation of DT can enhance the security of smart factories, with the potential for application during the design phase by providing engineers with tools to identify vulnerabilities within CPS specifications. They highlight that DTs can accompany their physical counterparts throughout a factory's lifecycle, thus strengthening CPS security.

Jbair et al. (2022) hypothesize that DT can analyze the behavior of cyber-physical systems, thereby enabling the prediction and assessment of cyber threats. The authors proposed a threat modelling method for cyber-physical systems, integrated with the DT tool VueOne, implemented on a prototype production line from Festo.

Thakur et al. (2023) address identity authentication issues in DT environments, critically analyzing a recently proposed blockchain-based two-factor authentication protocol, questioning its effectiveness. They proposed and verified a privacy-preserving three-factor authentication scheme for DT environments.

Holmes et al. (2021) emphasized that the expansion of DT technology into traditional industries, including manufacturing, construction, automotive, agriculture, and transportation, has highlighted its potential but has not sufficiently examined the risks associated with integration. Holmes et al. (2021) conducted a detailed analysis of the cybersecurity threats present within systems utilizing DT technology, exploring the potential of DT to function as a pivotal security component within cyber-physical systems.

3.3. VOSViewer study

At this stage, a keyword co-occurrence network map was developed based on the analyzed publications. The analysis encompassed keywords provided by authors and keywords indexed by the SCOPUS and WoS CC databases, with both sets analyzed collectively. The reference number of keywords was adopted according to approaches tested in previous research (Ciano et al., 2019). The inclusion criterion was set to five occurrences of a keyword, meaning

a keyword had to appear in at least five different publications to be included on the co-occurrence map. It is acknowledged that the choice of threshold is a subjective one, and that a higher threshold might have led to the exclusion of important aspects, while a lower threshold could have resulted in an excessive number of keywords, which would have complicated the map analysis.

The total number of keywords in the set of publications analyzed was 2007. Utilizing the VOSviewer software and implementing the aforementioned inclusion criterion, a co-occurrence map was derived (Fig. 2), comprising 123 nodes (each node representing a keyword that met the inclusion criterion) categorized into five thematic clusters. Each cluster is highlighted with a different color. The occurrence frequency of keywords was used as a weighting metric, with the size of each node reflecting the frequency of a keyword's appearance in the analyzed set. The proximity of individual elements indicates their more frequent co-occurrence in specific sets compared to more distant elements. The clusters identified based on keywords are presented in Table 4. The nomenclature of each cluster is intended to delineate a shared thematic domain addressed by the aggregated publications.

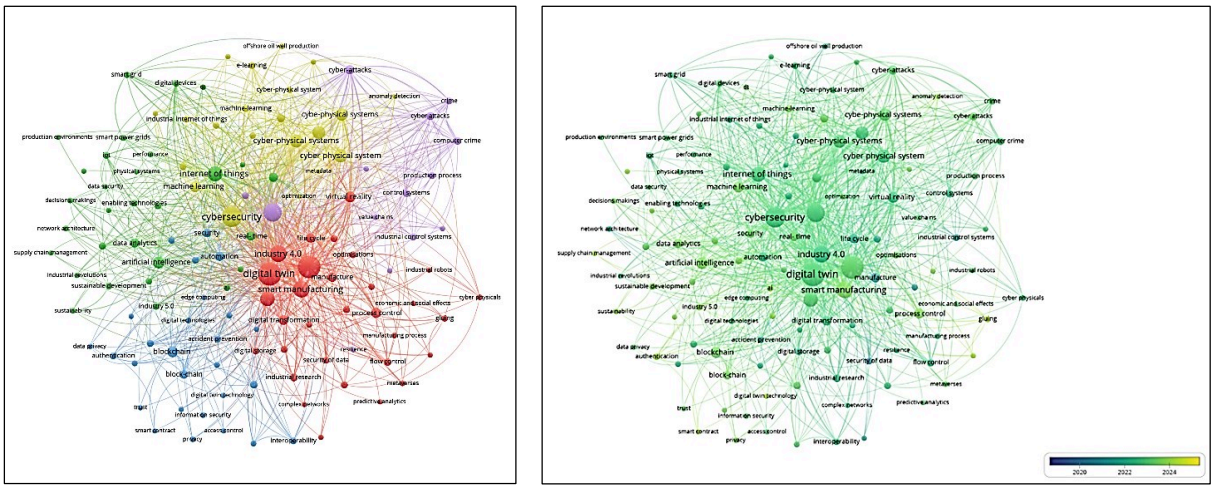

Figure 2. Co-occurrence network of author's keywords created in VOSviewer.

Source: own study.

Table 4.

Clusters based on the keywords discovered in VOSviewer

Cluster	Color	Cluster name
Cluster #1	red	The use of modern computer technologies of Industry 4.0 in the study of production processes in terms of improvement and impact on the social environment
Cluster #2	green	Application of artificial intelligence and digital technologies in sustainable development and optimization of production and logistics systems
Cluster #3	blue	Application of advanced digital technologies in securing the implementation of production processes
Cluster #4	yellow	Use of artificial intelligence and digital twins in optimization and security of production systems and education
Cluster #5	violet	Use of digital twins in the area of cyber security of production systems and supply chains

Source: own study.

All clusters are centrally located relative to the center of the map, indicating that several concepts form the core narrative in the studied area. Prominent concepts include DT, Industry 4.0, network security, and smart manufacturing – represented by the red cluster, and cybersecurity – represented by the yellow and violet clusters. The connections and central positions of these concepts suggest they constitute the main axis of current keyword discussions. Coupled with the relatively small number of publications, this indicates an early stage in the research cycle within this area.

Figure 2 also illustrates a map showing the identified nodes according to their popularity in discussions over time. The closer the color shifts toward yellow, the more popular the topic becomes from the perspective of 2025. There is no clear leader among current discussions, with all topics explored to a similar extent. This is likely due to the relatively short time the subject has existed in scholarly discourse. The earliest studies in the examined area date back to 2017, with significant growth in publications only starting from 2022.

The study also assessed mutual citation levels among the analyzed publications. The results indicate a lack of mutual citations, with all studies having over 50 citations from works not included in this analyzed set. This suggests authors investigating DT applications in the cybersecurity context of manufacturing processes do not commonly reference each other's work, possibly reflecting the early developmental stage of research on these topics.

3.4. LDA study

The selected publications were then analyzed using the LDAvis method. Analysis of abstracts provides a broader picture of the substantive content contained in an paper than analysis of keywords alone (Chuang et al., 2012). The LDA analysis began by identifying a list of irrelevant “stop words” that were removed. The list of these words can be found in Table 5.

Table 5.
List of the „stop words”

List of words omitted from the analysis
'and', 'or', 'also', 'use', 'paper', 'research', 'start', 'chapter', 'however', 'author', 'include', 'potential', 'need', 'explore', 'well', 'base', 'challenge', 'application', 'provide', 'propose', 'approach', 'present', 'include', 'potential', 'various', 'need'

Source: own study.

Subsequent research yielded a result indicating the existence of seven internally consistent yet significantly divergent topic areas, for which the consistency coefficient is 0.4173. When analyzing the abstracts without considering the list of "stop words", four topic areas were identified, yielding a consistency coefficient of 0.3571. The combined analysis of these findings indicates that the relationship between the use of DT, cyber security and manufacturing processes is associated with a limited number of specific topics. Figure 3 provides a visual representation of the identified topic areas.

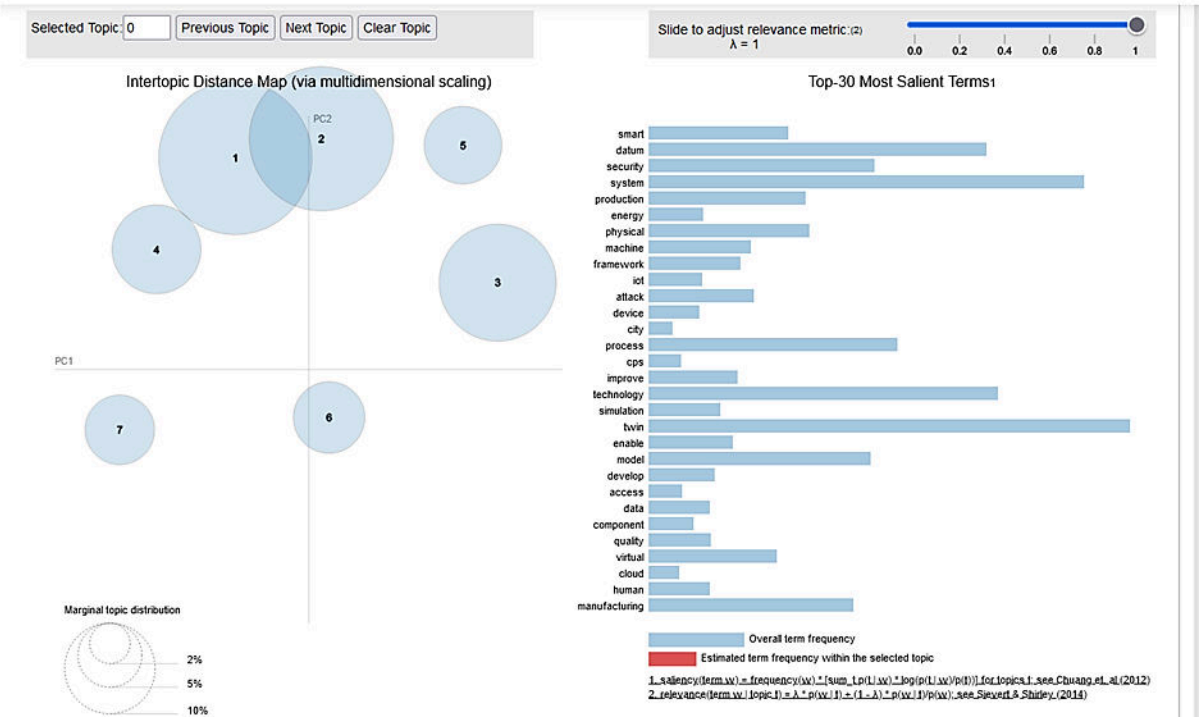

Figure 3. Topic one characteristics visualized with LDAVis.

Source: own study.

The center of the map indicates the theoretical ideal area combining the issues of cyber security, DT and manufacturing process. The sixth topic is located in closest proximity to the center. The remaining topic areas are distributed at a uniform distance from the central point on the map. The majority of these areas do not overlap, thereby suggesting their separation. The exceptions to this are Topic 1 and Topic 2, which demonstrate a clear commonality. Table 6 provides a nomenclature for the identified fields.

Table 6.
Clusters based on LDA method

Subject field	Subject area
Topic #1	The use of modern computer technologies (including DT) in the area of production
Topic #2	In the context of ensuring safety
Topic #3	Feasibility of using DT in ensuring the safety of production systems equipped with modern technologies
Topic #4	Exploration of a framework for the use of DT in intelligent manufacturing systems in the context of ensuring safety
Topic #5	Development/challenges of data analysis related to the management of computerized manufacturing systems
Topic #6	Pace related to data analysis in the context of optimizing production and ensuring business continuity of the manufacturing process
Topic #7	Ensuring digital security in access to production systems

Source: own study.

4. Discussion

The application of the VOSViewer software yielded five subject clusters, while the LDA analysis identified seven subject areas. The research was performed on an identical paper database. The analysis of the indicated keywords and the subjects covered in the publications revealed the similarities between the areas, as illustrated in Table 7. The thematic areas identified were found to be associated with concepts and trends that have emerged within the scientific and business communities.

Table 7.
Identified thematic fields

Related fields		Characteristics of common features	Reference to global aspects
Cluster#1 and Topic# 1		focusing on the use of modern technologies in the study of production processes, whether in the context of guiding improvements in these processes, ensuring the safety of their implementation or the impact on the social environment.	Digitalization of society / national strategies / social programs.
Cluster#2 and Topic#7		focusing on the application of digital technologies in sustainable development in relation to production systems, as well as urban environments.	Development of the concept of smart cities, smart manufacturing.
Cluster#3 and Topic#2 Topic#4	Research field #1	focusing on ensuring the security of implementation of production processes in terms of access protection or the use of modern digital technologies.	Increased threats of cyber attacks, hacking of databases of large multinational companies.
Cluster#4 and Topic#5		focusing on the implementation and integration of modern computer technologies in the area of DT.	Development of Industry 4.0 and Industry 5.0 concepts.
Cluster#5 and Topic#6	Research field #2	focusing on risk management of the implementation of production and logistics systems.	Trend particularly relevant after the occurrence of the COVID pandemic and the shortage of raw materials related to armed conflicts.

Source: own study.

All analyzed topics were related to the application of DT technology and associated modern computer technologies in manufacturing environments or their impact on the social environment. However, only two of them were directly related to ensuring the security of production processes. Therefore, these two areas are presented in detail below.

In the initial research domain, scholars concentrate on guaranteeing the security of production processes with regard to access protection and the implementation of contemporary digital technologies. Mihai emphasizes that when utilizing DT, it is imperative to address fundamental security principles such as privacy, authentication, integrity, and traceability. Mihai further contends that the DT structure should be intimately associated with or based on security measures (Mihai et al., 2022). Holmes introduces the concept of the Cyber Digital Twin (CDT), involving the application of DT for security analysis and threat monitoring.

This approach is crucial when conducting research in real environments is impossible or challenging. Enterprises stand to benefit from the ability to assess cybersecurity without impacting real-world processes or causing disruptions (Holmes et al., 2021). Eckhart and Ekelhart (2019) highlight the potential use of DT to enhance the security of Cyber-Physical Systems (CPS), defining DT as a virtual replica designed to support the physical environment through lifecycle phases (engineering, operation, end-of-life), process historical and real-time data, and test security measures. Holmes also discusses verifying selected event scenarios (e.g., hacker attacks, software malfunctions, physical device failures, continuity losses of suppliers/recipients) to assess their impact on production processes and validate defense systems (Holmes et al., 2021). Furthermore, Mihai et al. (2022) posit that DT can be conceptualized as a distinct intelligence modality, meticulously designed and refined for a comprehensive array of DT-related tasks, including the verification of hypothetical event scenarios. Eckhart and Ekelhart expanded their research to identify key DT applications in cybersecurity, including secure design of CPS, intrusion detection, detecting hardware and software misconfigurations, security testing, privacy, system testing and training (secure decommissioning), and secure and legal compliance (Eckhart, Ekelhart, 2019). In contrast, other authors have chosen to focus on specific solutions, often related to particular technologies, which are applied in production environments. Jbair's analysis of cybersecurity in controllers employed in Smart Manufacturing or Industry 5.0 resulted in the development of a methodology for enhancing controller security, comprising five steps: Asset Scoping, Attack Models, Attack Vector vs. Likelihood, Risk Matrix Definitions, and Mitigation Controls (Jiang et al., 2020). Thakur's team examined the applications of blockchain technology in securing access to CPS systems (Thakur et al., 2023).

Three main characteristics of CDT have been defined: firstly, the availability of the technology significantly reduces the cost of scenario implementation and verification, making the solution viable even for SMEs; secondly, integrity is examined in terms of system vulnerability to threats and the evaluation of the effectiveness of preventive actions, including pre-deployment verification of applications/software; thirdly, confidentiality emphasizes the need to secure CDT data to identify which threats are most dangerous, the least effective scenarios, and the least effective protective measures (Holmes et al., 2021).

The second research area addresses risk management in manufacturing and logistics systems. Mullet's research concentrated on the identification of cyber-physical threats in manufacturing systems and the implementation of preventive measures. He classified threats associated with modern computer technologies in manufacturing environments based on their area of occurrence: manufacturing/production, logistics, supervision, research and development, living areas, external physical, or external virtual (Mullet et al., 2021). In a similar vein, Alcaraz identified threats concerning four system layers: Layer 1 (CPS/IIoT), Layers 2 and 3 (Computing infrastructure, Virtualization systems, Computing techniques), and Layer 4 (HMIs). The most prevalent threats encompass software attacks, privilege escalations, private

information extraction, rogue components, Man-in-the-Middle (MitM) attacks, denial of service (DoS), and others (Alcaraz, Lopez, 2022). The threats most affecting operational requirements relate primarily to rogue component deployment, followed by MitM, DoS, and software attacks. The scope of threat impact is contingent on the DT deployment level and the centralization level of data/services.

In response to these threats, manufacturing companies have developed countermeasures to minimize their impact, including research into controlled industrial environments, software-defined network firewalls for Manufacturing Execution Systems, cybersecurity frameworks for IoT, direct-to-machine cybersecurity approaches, ensemble intelligence, and behavioral models for protecting industrial systems (Mullet et al., 2021). Significant areas for organizations utilizing DT include hardware and software security, infrastructure hardening and decoupling, identity, authentication, and authorization, deception, intrusion detection, situational awareness, response and recovery, event management, information sharing, trust management, privacy, governance, security management, traceability, auditing, accountability, training, and human aspects (Alcaraz, Lopez, 2022). Most approaches represent model solutions utilizing supportive methodologies and tools.

Mullet (2021) provides a comprehensive overview of best practices for organizational security in risk management processes. These include periodic risk analyses, user load monitoring, certification, business continuity planning, and defining alert states. In addition, solutions applied in production environments are of equal importance, including trust and integrity, cloud security, machine-to-machine security, data protection, software/firmware updates, access control (especially IoT devices), networks, protocols, encryption, monitoring, auditing, and configuration management (Mullet et al., 2021). This subject area is expanding in both scientific research and business applications. Existing studies highlight DT's potential in effectively managing production systems and processes, and as a tool supporting risk management across its various stages. The DT has even been identified as one of the most innovative solutions to emerge in recent years (Mullet et al., 2021).

The ensuing analysis yielded the following findings in response to the research questions.

RQ1: What fields in the application of DTs in the area of cyber security are studied in the literature?

The research identified five clusters (VOSviewer) and seven subject areas (LDA). A detailed analysis of the results led to the identification of two research areas for the application of DT in production processes in the area of cyber security. The primary area of focus pertains to the assurance of security in the execution of production processes, with specific emphasis on access protection and the utilization of digital technologies. The second area of research focuses on the management of risk in the operation of production and logistics systems.

RQ2: Are DTs applied in the area of risk management in manufacturing processes?

A considerable number of publications address the implementation of a risk management process for manufacturing processes and the assurance of security against cyber threats. However, in a limited number of publications, authors have indicated the potential for a more comprehensive approach, suggesting the exploration of not only the threats that affect the operation of DT, but also the utilization of DT as a tool to facilitate the risk management process. DT. As a digital representation of the real environment, DT contains a substantial amount of data on the process, which can be analyzed at various stages of risk management (hazard identification, risk assessment or risk estimation), as well as allowing verification of predicted event scenarios/solutions in order to select adequate preventive measures.

RQ3: What is the nature of DT application in the area of cybersecurity assurance?

DT is a digital representation of the production process under analysis. A key benefit of DT is its capacity to execute operations in a manner that does not disrupt the actual environment. The most common applications of DT in the cybersecurity field include: (1) the processing of real-time and historical data to make predictive predictions of intrusions, (2) testing activities leading to system security and providing training in this area, (3) the detection of intrusions and the detection of misconfiguration of hardware and software, (4) ensuring compliance with norms, standards and requirements, and (5) testing the security application of a selected component of a production/logistics system, such as controllers or Industry 4.0 technology. The utilisation of DT facilitates the implementation of specific metrics to assess the efficacy of cybersecurity risk management. These metrics may encompass a reduction in incident response time, decreased incident handling costs, or the eradication of incidents attributable to misconfiguration of production control systems.

RQ4: What are the opportunities and threats facing the implementation of DT in the area of cybersecurity?

Preliminary research undertaken in the field of cybersecurity has indicated the potential for the utilization of DT to be applicable in risk management activities. A notable aspect is the automation of actions, which eliminates the requirement for manual intervention (i.e. the slowing down or cessation of the process) by either physical systems or employees. Examples of such activities include: automatic testing of solutions/event scenarios, automatic detection of unwanted activities/intruders by identifying dissimilar behavior in the system, and the creation of a "dummy" system in the form of DT to redirect cyberattacks to it. The implementation of DTs in the domain of cyber security is confronted with several challenges, chief among them being the imperative to ensure the adequate security of the data contained within DTs. They furnish knowledge about particularly dangerous threats from the organization’s point of view, inadequate system security or protection deficiencies, as well as highlighting places in the system that are particularly vulnerable to attacks in real and digital environments. It is emphasized by numerous authors that the loss of significant information from the system's perspective can compromise its integrity. The utilization of DT to procure

crucial information about the system or to manipulate it in a manner that deviates from the organization's intended purpose can precipitate pivotal scenarios from an enterprise standpoint. The recurrence of such incidents can erode public confidence in DT technology, potentially undermining the validity of its implementation in production environments.

Within the framework of the described solutions, it is assumed that the data extracted, processed and analyzed from DT belongs to the enterprise in question and is only used within that enterprise. However, when data is exchanged with other entities, such as within the supply chain, the risk of misuse or unauthorized impact on the enterprise increases. This also poses challenges for further research on DT implementation in manufacturing environments.

The survey results suggest that little research has been conducted on using DT to ensure the safety of production processes. This research is typically conducted in a rather selective and unstructured manner. The measures companies take in this regard require a great deal of organizational commitment and are often costly. Consequently, they are most often applied in large organizations. Implementing DT in small organizations is also difficult due to the required infrastructure. Therefore, the use of DT to ensure the safety of production processes is likely to be limited to medium and large enterprises. However, if small companies were to implement DT, they could benefit from the aforementioned measures to support their operations, such as examining the process for potential risks and securing it accordingly. Highlighting the additional benefits of using DT could provide enterprises with further arguments in the decision-making process.

5. Conclusions

A systematic literature review was conducted to investigate the use of DT technology in cybersecurity for manufacturing processes. This review utilized bibliometric methods and advanced data analysis tools to identify key themes and research gaps. The research methodology, characterized by rigorous source selection and comprehensive quantitative and qualitative analyses, enabled an objective identification of key subject areas and research gaps. This approach ensured the attainment of the intended research objectives. The scientific value of the study lies in its thorough identification of gaps within the literature on cybersecurity approaches employing DT in manufacturing contexts. The study identifies specific research niches and emphasizes the interdisciplinary nature of the topic, which could significantly contribute to further advancements in this field.

The practical value of the research is connected to improving the effectiveness of cybersecurity risk management in manufacturing enterprises. The findings provide insights into the potential applications of DT as a tool for threat prediction, security testing, and optimization

of preventive measures without disrupting actual production systems. Future research directions should focus on addressing identified gaps and exploring the highlighted niches. This could include studies on practical applications of DT, such as risk management automation and developing methods for securing data collected within DT. Special attention should also be given to developing standards and methodologies for DT implementation in enterprises and researching the integration of DT with other information technologies.

References

1. Alcaraz, C., Lopez, J. (2022). Digital Twin: A Comprehensive Survey of Security Threats. *IEEE Communications Surveys, Tutorials*, *24*(3), 1475-1503. https://doi.org/10.1109/COMST.2022.3171465
2. Arksey, H., O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology*, *8*(1), 19-32. https://doi.org/10.1080/1364557032000119616
3. Bhatt, S., Pham, T.K., Gupta, M., Benson, J., Park, J., Sandhu, R. (2021). Attribute-Based Access Control for AWS Internet of Things and Secure Industries of the Future. *IEEE Access*, *9*, 107200-107223. https://doi.org/10.1109/ACCESS.2021.3101218
4. Blei, D., Ng, A., Jordan, M. (2003). Latent Dirichlet Allocation. *Journal of Machine Learning Research*, *3*, 993-1020.
5. Cai, Y., Starly, B., Cohen, P., Lee, Y.-S. (2017). Sensor Data and Information Fusion to Construct Digital-twins Virtual Machine Tools for Cyber-physical Manufacturing. *Procedia Manufacturing*, *10*, 1031-1042. https://doi.org/10.1016/j.promfg.2017.07.094
6. Chuang, J., Manning, C.D., Heer, J. (2012). Termite: Visualization techniques for assessing textual topic models. *Proceedings of the International Working Conference on Advanced Visual Interfaces*, 74-77. https://doi.org/10.1145/2254556.2254572
7. Ciano, M.P., Pozzi, R., Rossi, T., Strozzi, F. (2019). How *IJPR* has addressed 'lean': A literature review using bibliometric tools. *International Journal of Production Research*, *57*(15-16), 5284-5317. https://doi.org/10.1080/00207543.2019.1566667
8. Eckhart, M., Ekelhart, A. (2019). Digital Twins for Cyber-Physical Systems Security: State of the Art and Outlook. In: S. Biffl, M. Eckhart, A. Lüder, E. Weippl (Eds.), *Security and Quality in Cyber-Physical Systems Engineering* (pp. 383-412). Springer International Publishing. https://doi.org/10.1007/978-3-030-25312-7_14
9. Grieves, M., Vickers, J. (2017). Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems. In: F.-J. Kahlen, S. Flumerfelt, A. Alves (Eds.), *Transdisciplinary Perspectives on Complex Systems* (pp. 85-113). Springer International Publishing. https://doi.org/10.1007/978-3-319-38756-7_4

10. Holmes, D., Papathanasaki, M., Maglaras, L., Ferrag, M.A., Nepal, S., Janicke, H. (2021). Digital Twins and Cyber Security – solution or challenge? *2021 6th South-East Europe Design Automation, Computer Engineering, Computer Networks and Social Media Conference (SEEDA-CECNSM)*, 1-8. https://doi.org/10.1109/SEEDA-CECNSM53056.2021.9566277
11. Horn, N., Gampfer, F., Buchkremer, R. (2021). Latent Dirichlet Allocation and t-Distributed Stochastic Neighbor Embedding Enhance Scientific Reading Comprehension of Articles Related to Enterprise Architecture. *AI*, *2*(2), 179-194. https://doi.org/10.3390/ai2020011
12. Jbair, M., Ahmad, B., Maple, C., Harrison, R. (2022). Threat modelling for industrial cyber physical systems in the era of smart manufacturing. *Computers in Industry*, *137*, 103611. https://doi.org/10.1016/j.compind.2022.103611
13. Jiang, X., Pang, Z., Luvisotto, M., Candell, R., Dzung, D., Fischione, C. (2020). Delay Optimization for Industrial Wireless Control Systems Based on Channel Characterization. *IEEE Trans. on Ind. Inform.*, *16*(9), 5855-5865. *IEEE Transactions on Industrial Informatics*. https://doi.org/10.1109/TII.2019.2958708
14. Knoke, D., Yang, S. (2008). *Social Network Analysis*. SAGE Publications, Inc. https://doi.org/10.4135/9781412985864
15. Lis, A. (2018). Keywords Co-occurrence Analysis of Research on Sustainable Enterprise and Sustainable Organisation. *J. of Corp. Responsib. and Leadersh.*, *5*(2), *Article 2*. https://doi.org/10.12775/JCRL.2018.011
16. Lou, W., Qiu, J. (2014). Semantic information retrieval research based on co-occurrence analysis. *Online Information Review*, *38*(1), 4-23. https://doi.org/10.1108/OIR-11-2012-0203
17. Mihai, S., Yaqoob, M., Hung, D.V., Davis, W., Towakel, P., Raza, M., Karamanoglu, M., Barn, B., Shetve, D., Prasad, R.V., Venkataraman, H., Trestian, R., Nguyen, H.X. (2022). Digital Twins: A Survey on Enabling Technologies, Challenges, Trends and Future Prospects. *IEEE Communications Surveys, Tutorials*, *24*(4), 2255-2291. https://doi.org/10.1109/COMST.2022.3208773
18. Moez, A. (2009). *An open source, low-code machine learning library in Python, PyCaret*. https://www.pycaret.org
19. Morris, T.A. (2000). Structural relationships within medical informatics. *Proc. of the AMIA Symp.*, 590-594.
20. Mullet, V., Sondi, P., Ramat, E. (2021). A Review of Cybersecurity Guidelines for Manufacturing Factories in Industry 4.0. *IEEE Access*, *9*, 23235–23263. https://doi.org/10.1109/ACCESS.2021.3056650
21. Qian, C., Liu, X., Ripley, C., Qian, M., Liang, F., Yu, W. (2022). Digital Twin—Cyber Replica of Physical Things: Architecture, Applications and Future Research Directions. *Future Internet*, *14*(2), 64. https://doi.org/10.3390/fi14020064

22. Sievert, C., Shirley, K. (2014). LDAvis: A method for visualizing and interpreting topics. *Proceedings of the Workshop on Interactive Language Learning, Visualization, and Interfaces*, 63-70. https://doi.org/10.3115/v1/W14-3110
23. Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333-339. https://doi.org/10.1016/j.jbusres.2019.07.039
24. Thakur, G., Kumar, P., Deepika, Jangirala, S., Das, A.K., Park, Y. (2023). An Effective Privacy-Preserving Blockchain-Assisted Security Protocol for Cloud-Based Digital Twin Environment. *IEEE Access*, *11*, 26877-26892. https://doi.org/10.1109/ACCESS.2023.3249116
25. Visser, M., Van Eck, N.J., Waltman, L. (2021). Large-scale comparison of bibliographic data sources: Scopus, Web of Science, Dimensions, Crossref, and Microsoft Academic. *Quantitative Science Studies*, *2*(1), 20-41. https://doi.org/10.1162/qss_a_00112
26. Yeung, K. (2018). Algorithmic regulation: A critical interrogation. *Regulation, Governance*, *12*(4), 505-523. https://doi.org/10.1111/rego.12158

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ASSESSMENT OF THE FINANCIAL SITUATION OF LAND COUNTIES IN POLAND DEPENDING ON CHANGES IN THE NUMBER OF THEIR INHABITANTS

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Purpose: The aim of this article is to identify and assess the importance of changes in the number of inhabitants for shaping the financial situation of land counties in Poland.
Design/methodology/approach: The article identifies and assesses the significance of changes in the number of inhabitants for the development of the financial situation of land counties in Poland. The empirical material of the article concerns all land counties in Poland. The numerical data come from the Local Data Bank of the Central Statistical Office in Warsaw. The collected and organised empirical material was developed in descriptive, tabular, and graphical form, using the comparative analysis method. The article also uses basic measures of descriptive statistics, i.e., the mean, the coefficient of variation, and the minimum and maximum value. A point assessment of all diagnostic features analysed was also made that illustrates the financial situation in the studied groups of land counties in Poland, distinguished depending on the changes in the number of their inhabitants in the years 1995-2023, against the background of all land counties in the country for the years 2019-2023.
Findings: The conclusions of the analysis of the collected statistical data collected conducted in the article showed that the research hypothesis must be rejected. Namely, changes in the number of inhabitants do not constitute a significant factor that shapes the financial situation of land counties in Poland.
Originality/value: The originality of the article lies in its original approach to the analysis of the research issues. For the purposes of the research, a point assessment was made of all the diagnostic features illustrating the financial situation in the studied groups of land counties in Poland, distinguished depending on the changes in the number of their inhabitants in the years 1995-2023, against the background of all land counties in the country for the years 2019-2023, which is a new approach to the research problem undertaken in the article. The work is addressed mainly to local government officials responsible for public local government finances, as well as for the conditions, possibilities, and directions of local socioeconomic development of land counties in Poland.
Keywords: financial situation, land counties in Poland, changes in the number of inhabitants.
Category of the paper: research paper.

1. Introduction

Local government is one of the basic institutions of the public sector in every democratic country, including Poland, creating socio-economic development at the regional and local level. It is the most direct form of making and implementing many important decisions and public tasks by the local government community and is the administrative structure closest to the citizen. Among the public tasks of the local government, its own tasks are of great importance because they constitute the main element of its activities and their dominant role is the meaning and essence of local government. The framework and nature of the own tasks implemented by the local government are determined by two important areas of its public activity. The first is a set of activities that consist of the process of providing public services, while the second is a set of activities that aim to create conditions for the development of a given local government unit. These areas obviously coexist with each other, because the creation of development solutions depends on the efficient provision of public services. In turn, the effectiveness of the implementation of tasks (both their own and those assigned) by local government units is largely dependent on their effective financial management, and this can be guaranteed by the appropriate economic potential (Strzelecki, 2008; Dolewka, 2020; Grzebyk, Sołtysiak, Stec, Zając, 2020; Kata, Czudec, Zając, Zawora, 2022).

Therefore, in addition to providing public services at an appropriate level and with satisfaction for residents, a complementary part of local government is shaping conditions for a broadly understood development. However, the openness and goodwill of local government in this regard is not sufficient for this. Therefore, local government bodies must make an investment effort to increase the resources of municipal assets. This, in turn, requires guaranteeing permanent and reliable sources of financing, including current tasks, investment projects, and repayment and servicing of potential debt (Zioło, 2007; Błachut, Cierpiał-Wolan, Czudec, Kata, 2018; Kowalska, Możyłowski, Śmietanka, 2019; Dolewka, 2020).

The essence of the financial management of local government is not only the accumulation and expenditure of funds, but also, and perhaps above all, the performance of short- and long-term tasks, their analysis in order to make more effective decisions and eliminate existing deficiencies. The financial management of local government influences the development of many areas of its management, and at the same time, through the state of finances, it is a measure of the level of economic development of a given area. The lack of financial resources necessary to implement the assumed goals and tasks means that the local government unit experiences a decrease in its investment attractiveness and possibilities for further development. Local government financial management therefore includes a set of processes and phenomena related to the flow and distribution of funds. It therefore focusses on all activities related to planning, organisation, implementation, control and supervision in the area of collection and expenditure of these funds. Local government financial management is

a complex process, conducted in compliance with legislative requirements within the local government budget. Therefore, ensuring its efficient operation requires strict compliance with many legal acts, standards, and budget principles. The management of financial resources in local government takes place within the framework of the economic system and financial policy. The economic system is shaped by legal regulations and includes a structure of action that motivates rational decision-making. Local government financial policy, in turn, means the conscious and purposeful activity of its bodies, consisting in the selection of socioeconomic goals and tasks and their achievement through the selection of appropriate means and methods of implementation. It should be added that the verification of financial policy takes place within the framework of the budget policy of local government, consisting of the selection of sources and methods of collecting public revenues and directions and methods of implementing public expenditures necessary to achieve the assumed goals. Therefore, the budget policy implemented at a given level of local government consists in the purposeful and conscious use of the budget to achieve goals contributing to the implementation of the development policy of a given local government unit. Budget policy determines only a fragment of the time of financial policy treated as a process of continuous planning, and the entire planned financial policy is reflected in a multiyear financial forecast, which increases discipline in the implementation of each year's budget policy, and this applies in particular to investment expenditures, which usually go beyond one year of financing (Jastrzębska, 2005; Patrzałek, 2006; Kosek-Wojnar, Surówka, 2007; Sołtyk, 2017; Jędrzejewski, 2018; Miemiec, 2018; Dolewka, 2020; Łubina, 2020; Kata, Czudec, Zając, Zawora, 2022).

The management of public funds in local government is active and consists of creating conditions for obtaining income and its distribution and expenditure to achieve various competitive goals. The managers of such an economy are responsible for acting in accordance with the canons of economic art, i.e. making rational decisions, taking into account the efficiency of management. A climate of savings, pressure to eliminate all waste, and mismanagement should be a universal imperative. The residents of a given local government community are not only voters and consumers of public services, but also taxpayers who expect that their money allocated for public purposes will be properly and well managed. Financial management of local government units should therefore support rational spending of public funds and making appropriate decisions in the management of these funds. In addition, it should also: be focused on results achieved thanks to incurred expenditures, take into account the variability of environmental conditions, use methods of multi-year financial and investment forecasting, and introduce market mechanisms to the processes of providing local government public services. Such a management formula is defined as an integrated process of shaping income and expenditure in an annual and multi-year cycle, taking into account the cost-benefit calculation, using instruments of strategic management of a given local government unit. The growing scope of tasks carried out by local governments, with limited financial resources and high variability in the environment, forces the improvement of financial management

methods in these units. Due to changes taking place in the public sector management system, it is necessary to use methods and tools based on a long-term approach that allows the diagnosis of both opportunities and threats that may appear in the future. Thanks to this, it is possible to shape the development processes of a given area while maintaining the financial balance of the local government unit (Ziółkowski, Goleń, 2006; Miszczuk, Miszczuk, Żuk, 2007; Adamczyk, Dawidowicz, 2016; Dolewka, 2020; Kata, Czudec, Zając, Zawora, 2022; Ociepa-Kicińska, Gorzałczyńska-Koczkodaj, Brzozowska, Pluskota, 2022).

Identification of basic phenomena and problems occurring in the financial management of local governments and interpretation and assessment of their interdependencies are the basis for determining the existing state, i.e. a diagnosis of the financial situation of a local government unit is made in this way. It provides knowledge about the ability of the local government to bear the costs of its current operations and the possibility of financing development activities, and also allows for improving the decision-making process towards improving the efficiency of managing property resources. The financial situation of a local government unit is its financial status in a given period of time, being the result of the income it has and its structure, expenses and their structure, the degree of use of returnable funds, activity and effectiveness in obtaining extrabudgetary funds, as well as the efficiency of managing financial and material resources. Among the number of conditions shaping the financial management of a local government unit, including its financial situation, the most general distinction is made between exogenous and endogenous conditions and mixed conditions. In addition, it is also possible to distinguish certain common categories, which include social, economic, environmental, and spatial conditions, as well as institutional, legal, and political conditions (Ossowska, Ziemińska, 2010; Zawora, 2015; Świrska, 2016; Bień, 2017; Sierak, 2017; Standar, 2017; Sołtysiak, 2018; Stanny, Strzelczyk, 2018; Wójtowicz, 2018; Dolewka, 2020; Czudec, 2021; Kata, Czudec, Zając, Zawora, 2022).

2. Research aim, empirical material, and research methods

The aim of the article is to identify and assess the significance of changes in the number of inhabitants for the financial situation of land counties in Poland.

The article presents a research hypothesis, assuming that changes in the number of inhabitants constitute a significant factor in shaping the financial situation of land counties in Poland.

The empirical material of the article concerns all land counties in Poland. The numerical data come from the Local Data Bank of the Central Statistical Office in Warsaw. The collected and organised empirical material was developed in descriptive, tabular, and graphical form,

using the comparative analysis method. The article also uses basic measures of descriptive statistics, i.e. the mean, the coefficient of variation, and the minimum and maximum value.

To identify and assess the financial situation of land counties in Poland, the following diagnostic characteristics illustrating it in the years 2019-2023 were analysed:

- total revenues of county budgets per capita (PLN),
- own revenues of county budgets per capita (PLN),
- share of own revenues in total revenues of county budgets (%),
- total expenditures of county budgets per capita (PLN),
- investment expenditures of county budgets per capita (PLN),
- share of investment expenditures in total expenditures of county budgets (%).

When analysing the financial situation of the land counties in Poland, it was assumed that the leading feature in this respect is the change in the number of inhabitants, i.e. a significant increase, stagnation, or a significant decrease in this number. For the purposes of the research in the article, all the land counties in Poland were divided into three groups, that is:

- I – land counties with an increase in the number of inhabitants in the years 1995-2023 (these are units in which the population dynamics in the years 1995-2023, with the year 1995 = 100, is above 110.0);
- II – land counties with stagnation in the number of inhabitants in the years 1995-2023 (these are units in which the population dynamics in the years 1995-2023, with the year 1995 = 100, is from 90.0 to 110.0);
- III – land counties with a decrease in the number of inhabitants in the years 1995-2023 (these are units in which the population dynamics in the years 1995-2023, with the year 1995 = 100, is below 90.0).

In addition, the article included a point assessment of all diagnostic characteristics analysed illustrating the financial situation in the studied groups of land counties in Poland, distinguished depending on the changes in the number of their inhabitants in the years 1995-2023, against the background of all land counties in the country for the years 2019-2023. Individual diagnostic characteristics were compared with the average for all land counties in Poland, which was assumed to be 100 points, and their advantage or disadvantage in the counties studied was assessed accordingly. Then, all the points were summed and the average was calculated (Figure 1). It should be emphasised that this is a new approach to the research problem undertaken in the article.

3. Results

There is little variation between land counties in Poland in terms of the average value of total income per capita in the years 2019-2023, depending on changes in the number of their inhabitants. The average value of total income per capita in the years studied is the highest in the group of land counties with a decrease in the number of inhabitants in the years 1995-2023, where it exceeds the average for all land counties in Poland. On the other hand, in the group of land counties with stagnation in the number of inhabitants in the years 1995-2023, it is close to the average for all land counties in the country, and in the group of land counties with an increase in the number of inhabitants, it is the lowest (Table 1).

Table 1.
Total revenues of land county budgets per capita in Poland in 2019-2023 (PLN)

Specification	Land counties			
	Total	According to changes in the number of inhabitants in the years 1995-2023		
		I	II	III
Average	1546,3	1252,4	1513,0	1668,8
Variation coefficient V (%)	20,6	17,3	18,6	19,3
Minimum	868,3	889,6	885,4	868,3
Maximum	2822,6	1742,7	2717,6	2822,6

Explanations of the Table: I – land counties with an increase in the number of inhabitants in the years 1995-2023; II – land counties with a stagnation in the number of inhabitants in the years 1995-2023; III – land counties with a decrease in the number of inhabitants in the years 1995-2023.

Source: Central Statistical Office in Warsaw.

Both in the case of all land counties in Poland and in their separate groups, depending on the changes in the number of inhabitants in the years 1995-2023, the variation of this characteristic between individual counties is small, so its variability is low (Table 1).

Table 2.
Own revenues of land district budgets per capita in Poland in 2019-2023 (PLN)

Specification	Land counties			
	Total	According to changes in the number of inhabitants in the years 1995-2023		
		I	II	III
Average	555,3	600,0	557,0	541,0
Variation coefficient V (%)	22,7	22,3	24,3	20,0
Minimum	302,5	387,3	302,5	379,0
Maximum	1416,9	926,7	1416,9	1109,8

Explanations of the Table: I – land counties with an increase in the number of inhabitants in the years 1995-2023; II – land counties with a stagnation in the number of inhabitants in the years 1995-2023; III – land counties with a decrease in the number of inhabitants in the years 1995-2023.

Source: Central Statistical Office in Warsaw.

Based on the data in Table 2, it should be noted that there are no major differences between land counties in Poland in terms of the average value of their own revenues per capita in the years 2019-2023. In all the selected groups of land counties, depending on the changes in the number of inhabitants in the years 1995-2023, the average value of the own revenues of the county budgets per capita in the period under review is similar and close to the average for all land counties in the country.

It should be added that the differentiation of this characteristic between individual land counties is small, so its variability is small and this applies to both all land counties in Poland and their selected groups, depending on the changes in the number of inhabitants in the years 1995-2023 (Table 2).

Table 3.
Share of own revenues in total revenues of the budgets of land counties in Poland in 2019-2023 (%)

Specification	Land counties			
	Total	According to changes in the number of inhabitants in the years 1995-2023		
		I	II	III
Average	37,0	48,8	37,5	33,2
Variation coefficient V (%)	22,6	19,5	19,0	18,2
Minimum	21,9	30,7	21,9	22,2
Maximum	66,8	66,8	58,4	54,5

Explanations of the Table: I – land counties with an increase in the number of inhabitants in the years 1995-2023; II – land counties with a stagnation in the number of inhabitants in the years 1995-2023; III – land counties with a decrease in the number of inhabitants in the years 1995-2023.

Source: Central Statistical Office in Warsaw.

In Poland, there is a difference between land counties in terms of their share of own revenues in total revenues in the years 2019-2023, depending on changes in the number of their inhabitants. On average, the share of own revenues in the total revenues of land counties' budgets in the years under review is the highest in the group of land counties with an increase in the number of inhabitants, where it exceeds the average for all land counties in Poland. On the other hand, in the group of land counties with stagnation in the number of inhabitants in the years 1995-2023, it is the closest to the average for all land counties in the country, while in the group of land counties with a decrease in the number of inhabitants it is the lowest (Table 3).

In addition, it should be noted that both in the case of all land counties in Poland and in their selected groups, depending on the changes in the number of inhabitants in the years 1995-2023, the differentiation of this characteristic between individual counties is small and therefore its variability is low (Table 3).

The data in Table 4 indicate that there is little variation between the land counties in Poland in terms of the average value of total expenditure per capita in the years 2019-2023, depending on changes in the number of their inhabitants. The average value of total expenditure per capita in the years studied is the highest in the group of land counties with a decrease in the number

of inhabitants in the years 1995-2023, where it exceeds the average for all land counties in Poland. On the other hand, in the group of land counties with stagnation in the number of inhabitants in the years 1995-2023, it is the closest to the average for all land counties in the country, and in the group of land counties with an increase in the number of inhabitants, it is the lowest.

Table 4.
Total expenditure of land county budgets per capita in Poland in 2019-2023 (PLN)

Specification	Land counties			
	Total	According to changes in the number of inhabitants in the years 1995-2023		
		I	II	III
Average	1522,9	1238,6	1486,3	1646,9
Variation coefficient V (%)	21,2	18,6	19,2	20,0
Minimum	814,7	870,5	814,7	847,9
Maximum	2859,2	1688,8	2651,2	2859,2

Explanations of the Table: I – land counties with an increase in the number of inhabitants in the years 1995-2023; II – land counties with a stagnation in the number of inhabitants in the years 1995-2023; III – land counties with a decrease in the number of inhabitants in the years 1995-2023.

Source: Central Statistical Office in Warsaw.

In both the case of all land counties in Poland and in their selected groups, depending on changes in the number of inhabitants in the years 1995-2023, the differentiation of this characteristic between individual counties is small and, therefore, its variability is low (Table 4).

Table 5.
Investment expenditure of land county budgets per capita in Poland in 2019-2023 (PLN)

Specification	Land counties			
	Total	According to changes in the number of inhabitants in the years 1995-2023		
		I	II	III
Average	290,5	266,8	275,9	315,4
Variation coefficient V (%)	49,5	27,7	44,9	55,5
Minimum	90,6	139,1	90,6	102,1
Maximum	1051,6	446,5	1051,6	996,0

Explanations of the Table: I – land counties with an increase in the number of inhabitants in the years 1995-2023; II – land counties with a stagnation in the number of inhabitants in the years 1995-2023; III – land counties with a decrease in the number of inhabitants in the years 1995-2023.

Source: Central Statistical Office in Warsaw.

Based on the data in Table 5, it should be noted that there are no major differences between land counties in Poland in terms of the average value of investment expenditure per capita in the years 2019-2023. In all the distinguished groups of land counties, depending on the changes in the number of inhabitants in the years 1995-2023, the average value of investment expenditure of the county budgets per capita in the period under review is similar and close to the average for all land counties in the country.

In turn, the variability of this feature between individual land counties is quite large, and this applies to all land counties in Poland as well as to their separate groups, depending on the changes in the number of inhabitants in the years 1995-2023. Therefore, the variability of this feature is also quite large, but it is the smallest in the group of land counties with an increase in the number of inhabitants in the years 1995-2023, i.e., this group of counties is the most homogeneous in this respect (Table 5).

The land counties in Poland are not differentiated in terms of the share of investment expenditure in total expenditure in the years 2019-2023. On average, the share of investment expenditure in total expenditure of the land counties' budgets in the years studied, in all their separate groups, depending on the changes in the number of inhabitants in the years 1995-2023, is similar and close to the average for all land counties in the whole country (Table 6).

Table 6.
Share of investment expenditure in total expenditure of the budgets of land counties in Poland in 2019-2023 (%)

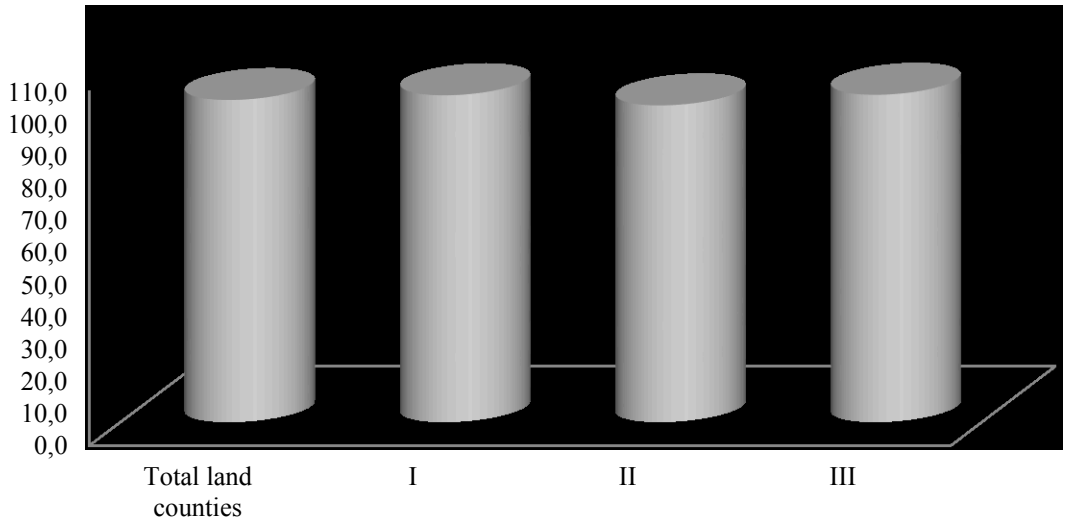
Specification	Land counties			
	Total	According to changes in the number of inhabitants in the years 1995-2023		
		I	II	III
Average	19,1	21,9	18,7	18,7
Variation coefficient V (%)	40,7	27,8	40,9	43,7
Minimum	5,9	10,9	5,9	6,4
Maximum	44,4	38,7	44,4	42,4

Explanations of the Table: I – land counties with an increase in the number of inhabitants in the years 1995-2023; II – land counties with a stagnation in the number of inhabitants in the years 1995-2023; III – land counties with a decrease in the number of inhabitants in the years 1995-2023.

Source: Central Statistical Office in Warsaw.

It should be added that, both in the case of all land counties in the whole of Poland and in their separate groups, depending on the changes in the number of inhabitants in the years 1995-2023, the differentiation of this feature between individual units is quite large. Therefore, its variability is also quite large, and it is the smallest in the group of land counties with an increase in the number of inhabitants in the years 1995-2023, i.e., this group of counties is the most homogeneous in this respect (Table 6).

Figure 1 presents the results of the point assessment concerning all the diagnostic features illustrating the financial situation in the examined groups of land counties in Poland, distinguished depending on the changes in the number of their inhabitants in the years 1995-2023, against the background of all land counties in the country for the years 2019-2023. On its basis, it can be seen that there are no major differences in this respect between land counties in Poland. Namely, in all the distinguished groups of land counties, depending on the changes in the number of their inhabitants in the years 1995-2023, the financial situation in the examined period is similar and close to the average for all land counties in the entire country.



Explanations of the figure: I – land counties with an increase in the number of inhabitants in the years 1995-2023; II – land counties with a stagnation in the number of inhabitants in the years 1995-2023; III – land counties with a decrease in the number of inhabitants in the years 1995-2023.

Figure 1. Point evaluation of all diagnostic features illustrating the financial situation in the studied groups of land counties in Poland, distinguished according to changes in the number of their inhabitants in the years 1995-2023, against the background of all land counties in the country for the years 2019-2023 (counties in Poland = 100.0 points)

Source: Own study.

In connection with the above, the research hypothesis put forward in the article, assuming that changes in the number of inhabitants constitute a significant factor shaping the financial situation of land counties in Poland, should be rejected.

4. Summary and conclusions

The analysis of the collected statistical data conducted in the article allows us to conclude that:

- land counties in Poland are slightly differentiated in terms of the average value of total income per capita in the years 2019-2023, depending on the changes in the number of their inhabitants, with this value being the highest in the group of land counties with a decrease in the number of inhabitants in the years 1995-2023, and the lowest in the group of land counties with an increase in this number;
- in Poland, there are no major differences between land counties in terms of the average value of own income per capita in the years 2019-2023;
- land counties in Poland are differentiated in terms of their share of own income in total income in the years 2019-2023, depending on the changes in the number of their inhabitants, with this share being the highest in the group of land counties with

an increase in the number of inhabitants in the years 1995-2023 and the lowest in the group of land counties with a decrease in this number;

- there is a slight variation between the land counties in Poland in terms of the average value of total expenditure per capita in the years 2019-2023, depending on the changes in the number of their inhabitants, with this value being the highest in the group of land counties with a decrease in the number of inhabitants in the years 1995-2023, and the lowest in the group of land counties with an increase in this number;
- land counties in Poland are not differentiated in terms of the average value of investment expenditure per capita, as well as in terms of the share of investment expenditure in the total expenditure of their budgets in the years 2019-2023.

The groups of land counties distinguished in the article, depending on the changes in the number of their inhabitants, are therefore slightly differentiated only in terms of the average value of total income and expenditure per capita, as well as in the case of the share of own income in total income. On the other hand, the remaining analysed features illustrating their financial situation in the years studied are similar, and there are no major differences between them in this respect. Therefore, they are characterised by a similar financial situation, and at the same time very close to the average for all land counties in the entire country. Therefore, changes in the number of inhabitants do not constitute a significant factor that shapes the financial situation of land counties in Poland. Therefore, the research hypothesis presented in the article should be rejected.

It should be added that the conclusions from the analysis of the collected statistical data conducted in the article provide important and up-to-date knowledge that may be useful for local government officials responsible for public local government finances, as well as for the conditions, possibilities, and directions of development of land counties in Poland. This also justifies the need to continue similar studies and analyses, mainly for the purpose of their verification and updating.

References

1. Adamczyk, A., Dawidowicz, D. (2016). Wartość informacyjna wskaźników oceny kondycji finansowej jednostek samorządu terytorialnego. *Ekonomiczne Problemy Usług, 25*, pp. 25-36. https://doi.org/10.18276/epu.2016.125-02
2. Bień, W. (2017). Ocena kondycji finansowej gmin województwa małopolskiego w latach 2007-2016. *ZN UE w Katowicach*. *Współczesne Finanse, 1, nr 345*, pp. 45-62.
3. Błachut, B., Cierpiał-Wolan, M., Czudec, A., Kata, R. (2018). *Wydatki inwestycyjne jednostek samorządu terytorialnego a rozwój przedsiębiorczości w regionie Polski południowo-wschodniej*. Rzeszów: Urząd Statystyczny w Rzeszowie.

4. Czudec, A. (2021). Finanse jednostek samorządu terytorialnego w okresie pandemii. *Finanse Komunalne, 5*, pp. 7-18.
5. Dolewka, Z. (2020). *Gospodarowanie zasobami finansowymi w polskim samorządzie terytorialnym*. Łódź/Kraków: Wydawnictwo Uniwersytetu Łódzkiego.
6. Grzebyk, M., Sołtysiak, M., Stec, M., Zając, D. (2020). *Społeczne, ekonomiczne i środowiskowe uwarunkowania gospodarki finansowej samorządu lokalnego (przykład województwa podkarpackiego)*. Poznań: Bogucki Wydawnictwo Naukowe.
7. Jastrzębska, M. (2005). *Polityka budżetowa jednostek samorządu terytorialnego*. Gdańsk: Wydawnictwo Uniwersytetu Gdańskiego.
8. Jędrzejewski, L. (2018). *Gospodarka finansowa samorządu terytorialnego. Tendencje, problemy i dylematy modelu państwa i demokracji*. Gdańsk: Wydawnictwo Uniwersytetu Gdańskiego.
9. Kata, R., Czudec, A., Zając, D., Zawora, J. (2022). *Gospodarka finansowa jednostek samorządu terytorialnego–wybrane zagadnienia*. Rzeszów: Wydawnictwo Uniwersytetu Rzeszowskiego.
10. Kosek-Wojnar, M., Surówka, K. (2007). *Podstawy finansów samorządu terytorialnego*. Warszawa: PWN.
11. Kowalska I., Możyłowski P., Śmietanka T. (eds.) (2019). *Funkcjonowanie jednostek samorządu terytorialnego w wymiarze finansowo-prawnym*. Radom: Instytut Naukowo-Wydawniczy Spatium, p. 37.
12. Łubina, J. (2020). Problematyka gospodarki finansowej jednostek samorządu terytorialnego w kontekście realizacji zadań publicznych. *Prawo Budżetowe Państwa i Samorządu, no. 2(8)*, pp. 129-150.
13. Miemiec, W. (ed.). (2018). *Prawo finansów publicznych z kazusami i pytaniami*. Warszawa: Wolters Kluwer, p. 224.
14. Miszczuk, A., Miszczuk, M., Żuk, K. (2007). *Gospodarka samorządu terytorialnego*. Warszawa: PWN.
15. Ociepa-Kicińska, E., Gorzałczyńska-Koczkodaj, M., Brzozowska, K., Pluskota, P. (2022). Ocena kondycji finansowej jednostek samorządu terytorialnego w obliczu pandemii COVID-19 na przykładzie województw samorządowych w Polsce. *Rozwój Regionalny i Polityka Regionalna, 59*, pp. 149-165.
16. Ossowska, L., Ziemińska, A. (2010). Kondycja finansowa gmin wiejskich i miejsko-wiejskich województwa pomorskiego. *Journal of Agribusiness and Land Development, no. 4(18)*, pp. 73-85.
17. Patrzałek, L. (2006). Polityka budżetowa. In: S. Winiarski (ed.), *Polityka gospodarcza*. Warszawa: PWN, pp. 380-397.
18. Sierak, J. (2017). Regionalne zróżnicowanie wielkości i dynamiki dochodów gmin i miast na prawach powiatu – analiza wskaźnikowa dla lat 2000-2014. *Finanse Komunalne, no. 1-2*, p. 77.

19. Sołtyk, P. (2017). Uwarunkowania efektywności systemu kontroli gospodarki finansowej jednostek samorządu terytorialnego. *Studia i Prace WNEIZ US, no. 47/3*, pp. 381-393.
20. Sołtysiak, M. (2018). Ocena wiedzy i aktywności przedstawicieli pokolenia X w przedmiocie budżetu jednostek samorządu terytorialnego. *Zeszyty Naukowe Wydziału Nauk Ekonomicznych Politechniki Koszalińskiej, no. 22*, pp. 325-341.
21. Standar, A. (2017). Ocena kondycji finansowej gmin oraz jej wybranych uwarunkowań na przykładzie województwa wielkopolskiego przy wykorzystaniu metody TOPSIS. *Wieś i Rolnictwo, no. 2(175)*, pp. 69-92.
22. Stanny, M., Strzelczyk, W. (2018). *Kondycja finansowa samorządów lokalnych a rozwój społeczno-gospodarczy obszarów wiejskich. Ujęcie przestrzenne*. Warszawa: Scholar.
23. Strzelecki, Z. (ed.) (2008). *Gospodarka lokalna i regionalna*. Warszawa: PWN.
24. Świrska, A. (2016). Czynniki determinujące efektywne zarządzanie finansami samorządowymi (na przykładzie gmin powiatu siedleckiego). *Polityki Europejskie, Finanse i Marketing, 16(65)*, pp. 88-99.
25. Wójtowicz, K. (2018). Znaczenie wybranych czynników ekonomiczno-społecznych dla kształtowania stabilności fiskalnej gmin miejskich w Polsce. *Acta Universitatis Lodziensis. Folia Oeconomica, vol. 334(2)*, pp. 213-234.
26. Zawora, J. (2015). Analiza wskaźnikowa w procesie zarządzania finansami samorządowymi. *Zarządzanie Finansami i Rachunkowość, 4*, pp. 33-45.
27. Zioło, M. (2007). Aktywność inwestycyjna samorządu terytorialnego w Polsce w latach 1999-2005. In: K. Piotrkowska-Marczak, K. Kietlińska (eds.), *Harmonizacja finansów publicznych w skali narodowej i europejskiej* (p. 493). Warszawa: Difin.
28. Ziółkowski, M., Goleń, M. (2006). Zarządzanie strategiczne rozwojem lokalnym. In: H. Sochacka-Krysiak (ed.), *Zarządzanie gospodarką i finansami gminy* (pp. 55-100). Warszawa: SGH.

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THE DEVELOPMENT LEVEL OF NON-AGRICULTURAL ECONOMIC ACTIVITY OF INDIVIDUALS AND THE FINANCIAL SITUATION OF RURAL MUNICIPALITIES IN POLAND

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Purpose: The aim of the article is to identify and assess the importance of the activity of natural persons in the development of non-agricultural economic activity for the financial situation of rural communes in Poland.
Design/methodology/approach: The significance of the activity of individuals in the development of non-agricultural economic activity was identified and evaluated for the financial situation of rural communes in Poland. The empirical material of the article concerns all rural communes in Poland. The numerical data come from the Central Statistical Office Local Data Bank in Warsaw and concern five years, i.e. 2018-2022. The collected and organised empirical material was developed in descriptive, tabular, and graphical form, using the comparative analysis method. For the purposes of the research, the indicator of the level of development of nonagricultural economic activity of individuals in a given local government unit (commune) was used. A point assessment of the financial situation in the studied groups of rural communes was also made against the background of all rural communes in the entire country.
Findings: The analysis of the collected statistical data and the point assessment of the financial situation in the examined groups of rural communes against the background of all rural communes in Poland for the years 2018-2022 confirmed the research hypothesis put forward in the article, which assumes that the financial situation of rural communes in Poland is related to the activity of natural persons in the development of non-agricultural economic activity, and it is clearly the best in the group of units with high activity of natural persons in this area.
Originality/value: The originality of the article lies in its original approach to the analysis of the research issues. For the purposes of the research, an indicator of the level of development of non-agricultural economic activity of individuals in a given local government unit (municipality) was used, which is a new approach to the research problem undertaken in the article. Additionally, a point evaluation of all diagnostic features illustrating the financial situation in the studied groups of rural communes against the background of all rural communes in Poland for the years 2018-2022. The work is addressed mainly to local government officials responsible for public local government finances, as well as for the conditions, possibilities, and directions of local socioeconomic development of rural communes in Poland.
Keywords: non-agricultural economic activity of individuals, financial situation, rural communes in Poland.
Category of the paper: research paper.

1. Introduction

Nowadays, agriculture has ceased to play a fundamental role in the economy and social sphere of rural areas. In rural areas, in addition to agricultural activity, new non-agricultural forms of economic activity are increasingly appearing. As a result, both the level and dynamics of development of these areas are no longer determined mainly by agriculture, and are increasingly determined by non-agricultural economic activity. The development of non-agricultural economic activity in rural areas is one of the priorities of the economic policy of the European Union, including Poland. This results from the fact that it positively changes rural areas, improving the quality, standard and conditions of life of residents and maintaining their social, economic, environmental and cultural vitality, which is extremely important from the point of view of the concept of multifunctional and sustainable development. The premises for the development of non-agricultural economic activity in rural areas result from its significant importance in the economy and society. It brings financial benefits not only to those directly involved in it, but also to the commune itself, as a local government unit, in the form of revenues from fees and taxes, which are part of its budget revenues. It also makes the commune more self-sufficient in terms of access to various products and services, helps attract investors from outside and create new business entities, establish new and develop existing institutions or organisations, and improves the image of the commune outside and counteracts the depopulation of rural areas. In connection with this, a whole set of factors appears, operating on the basis of feedback and multiplier mechanisms, leading to the acceleration of local socioeconomic development (Hybel, 2000; Kłodziński, Rosner, 2000; Zając, 2014; Kulawiak, 2022).

Therefore, non-agricultural economic activity transforms a monofunctional village into a multifunctional one, thus contributing to the economic activation of rural areas and dynamizing the process of their socio-economic development. It can be carried out by both non-agricultural and agricultural populations. It can be related to agriculture or completely unrelated to it. It can also be a registered or unregistered activity (Zając, 2014).

In the process of multifunctional development of rural areas and creation of new jobs, non-agricultural economic activity of individuals plays a special role. It is usually carried out on a small scale, is not very harmful to the natural environment and works well in agri-food processing, crafts and in the service of tourism and, agritourism, and if properly stimulated and directed, can become an important source of income for the rural and agricultural population and for local governments (Kamińska, 2011).

The main factors stimulating the development of non-agricultural economic activity in rural areas include: geographical location (including the vicinity of a city, the presence of an important communication route, natural, landscape and tourist values), human and social capital and financial capital, as well as supporting activities on the part of local government.

On the other hand, the most important barriers to its development are: the demand barrier and unfavourable demographic structures, especially in peripheral rural areas. Important factors positively influencing the development of non-agricultural economic activity in rural areas are therefore shaped to a greater or lesser extent by the development policy pursued by local government (Kłodziński, Rosner, 2000; Kamińska, 2011; Kłodziński, 2012; Rosner, 2012; Duczkowska-Małysz, Duczkowska-Piasecka, 2014; Kopacz-Wyrwał, 2015; Zarębski, 2015; Błachut, Cierpiał-Wolan, Czudec, Kata, 2018; Kulawiak, 2022).

Local government is the most direct form of making and implementing important decisions by a self-government community formed by all the residents of a given region (voivodeship) or locamrówl environment (county, commune). It is a key institution responsible for implementing many very important tasks that serve to meet the needs of residents, as well as creating social and economic development in the regional and local system. The effectiveness of implementing tasks by local government units depends largely on effective financial management, and the guarantee of their implementation is the appropriate economic potential (Dolewka, 2020; Grzebyk, Sołtysiak, Stec, Zając, 2020; Kata, Czudec, Zając, Zawora, 2022).

The financial management of a commune consists in collecting income and revenues and making expenditures and expenses in order to perform its own and assigned tasks, while it determines its development and competitiveness and secures the fulfilment of the needs of residents. In assessing the income side of the commune budget, it is important to examine changes in the amount of income, its dynamics and structure, and spatial differentiation. On the other hand, based on the analysis of the expenditure side of the budget, it can be determined to what extent financial resources are allocated to solving current problems and to what extent to the promotion and development of the commune and to the improvement and growth of its competitiveness. It should be added that the analysis of the spatial differentiation of the level of budget revenues indicates that high incomes of communes are not only the result of the resourcefulness of local government authorities, but also result from, among other things, the location of capital and enterprises, changes in the number of inhabitants, the condition of infrastructure, the neighbourhood or the presence of cities and tourist attractiveness (Hybel, 2010; Grzebyk, Sołtysiak, Stec, Zając, 2020; Kata, Czudec, Zając, Zawora, 2022).

Financial management in local government therefore focusses on all activities related to planning, organisation, implementation, control and supervision in the area of collecting and spending budget funds. Local government financial policy means in turn the conscious and purposeful activity of its bodies, consisting of the selection of socio-economic goals and tasks and their achievement through the selection of appropriate means and methods of implementation (Dolewka, 2020).

Investment expenditure in the financial economy of municipalities, in addition to their own revenues, is an important factor characterising their development possibilities. The wealth of municipalities affects their investment possibilities. Units with higher budget revenues per capita usually also have greater investment possibilities. A larger share of own revenues in total

budget revenues allows for more free disposal of financial resources and thus creates the possibility of allocating larger amounts for investments (Błachut, Cierpiał-Wolan, Czudec, Kata, 2018; Dziemianowicz, Kargol-Wasiluk, Bołtromiuk, 2018; Czudec, 2021).

The financial management of public sector entities should support rational spending of public funds and making appropriate decisions in the management of these funds. A properly managed entity should develop the so-called "good indicators" in the long term, i.e. those that indicate its development. The concept of the financial situation of a local government unit deserves special attention, interpreted as the ability of the local government to balance recurring expenditure needs with recurring sources of income, while simultaneously implementing tasks resulting from legal regulations, which are to serve to further increase income and maximise public utility for its residents (Adamczyk, Dawidowicz, 2016; Kowalska, Możyłowski, Śmietanka, 2019; Ociepa-Kicińska, Gorzałczyńska-Koczkodaj, Brzozowska, Pluskota, 2022).

The financial situation of a local government means the state of its economy in the financial dimension. It is a picture of the financial condition, subject to assessment (financial standing). The financial assessment can be carried out by an internal entity (local government financial services, auditors) or external entities with supervisory and control powers (regional audit chambers, Supreme Audit Office) or specialized market agencies (analyses, preparation of ratings). The results of financial analyses pose certain challenges for local government authorities, stimulate thinking based on economic logic, and facilitate a deeper assessment of the economy and financial policy. The assessment of the financial condition is a form of diagnosis that allows for the improvement of the decision-making process towards improving the efficiency of managing property resources (Sierak, 2017; Standar, 2017; Dolewka, 2020).

In defining the financial situation of a local government unit, the following are most often emphasised: the ability to finance services in a continuous manner, the comprehensiveness of sound finances, the ability to repay liabilities, and maintaining the current level of services while maintaining resistance to the risk of changes occurring over time. It seems that the most accurate interpretation of the financial situation of a local government unit is related to its ability to meet its financial obligations on time and to maintain the services provided to the local community (Filipiak, 2011; Dylewski, Filipiak, Gorzałczyńska-Koczkodaj, 2011; Wiśniewski, 2011; Kopyściański, Rólczyński, 2014; Kotowska, 2016; Natrini, Taufiq Ritonga, 2017; Ociepa-Kicińska, Gorzałczyńska-Koczkodaj, Brzozowska, Pluskota, 2022).

The financial situation of a commune is its financial state in a given period of time, which is the result of income and its structure, expenditure and its structure, the degree of use of returnable funds, activity and effectiveness in obtaining extra-budgetary funds, as well as the efficiency of managing financial and material resources. Local authorities should care about the good financial situation of a given territorial unit, as it is a component of its competitiveness. In addition, it is evidenced, among other things, the ability to perform tasks, achieve budget balance, as well as increase assets and to implement and satisfy the needs of residents. Among the various conditions shaping the financial management of a territorial self-

government unit, including its financial situation, the most general distinction is made between exogenous and endogenous conditions and mixed conditions. In addition, certain common categories can also be distinguished, which include social, economic, environmental, and spatial conditions, as well as institutional, legal, and political conditions. The catalogue of such factors is sometimes extended to include events whose effects cannot be predicted and which may fundamentally change the economic situation and operating conditions of local government units. This event in 2020 was the emergence of the coronavirus pandemic. It should be added that the analysis of the financial situation of a local government unit provides information about its current and future property and financial situation and also allows for determining its development opportunities and prospects (Ossowska, Ziemińska, 2010; Zawora, 2015; Świrska, 2016; Bień, 2017; Standar, 2017; Stanny, Strzelczyk, 2018; Wójtowicz, 2018; Czudec, 2021).

2. Research aim, empirical material, and research methods

The aim of the article is to identify and assess the significance of the activity of individuals in the development of non-agricultural economic activity for the financial situation of rural communes in Poland.

The article presents a research hypothesis, which assumes that the financial situation of rural communes in Poland is related to the activity of individuals in the development of non-agricultural economic activity, and it is clearly the best in the group of units with high activity of individuals in this area.

The empirical material of the article concerns all rural communes in Poland. The numerical data come from the Local Data Bank of the Central Statistical Office in Warsaw and concern five years, i.e. 2018-2022. The collected and organised empirical material was developed in descriptive, tabular, and graphical form, using the comparative analysis method. The article also uses basic measures of descriptive statistics, i.e. the mean, the coefficient of variation, and the minimum and maximum value.

For the purpose of research, the article compiles and uses an indicator of the level of development of non-agricultural economic activity of individuals in a given local government unit (municipality). The construction of this indicator consists in the fact that the number of business entities of individuals in a given local government unit (municipality) in the year under review (i.e. 2022) was converted per 100 inhabitants of working age. It should be emphasised that this is a new approach to the research problem undertaken in the article.

Taking into account the above assumptions, all rural communes in Poland were divided into three groups, depending on the activity of individuals in the development of non-agricultural economic activity, i.e.:

- Group I – rural communes in which the level of development of non-agricultural economic activity of individuals is high (the number of business entities of individuals per 100 inhabitants of working age in 2022 was 16.0 and more).
- Group II – rural communes in which the level of development of non-agricultural economic activity of individuals is moderate (the number of business entities of individuals per 100 inhabitants of working age in 2022 was from 8.0 to 16.0).
- Group III – rural communes in which the level of development of non-agricultural economic activity of individuals is low (the number of business entities of individuals per 100 inhabitants of working age in 2022 was up to 8.0).

To identify and assess the financial situation of rural communes in Poland, the following diagnostic features were analysed that illustrate it in the years 2018-2022:

- total revenues of communes' budgets per capita (PLN);
- own revenues of communes' budgets per capita (PLN);
- share of own revenues in total revenues of communes' budgets (%);
- total expenditures of communes' budgets per capita (PLN);
- investment expenditures of communes' budgets per capita (PLN);
- share of investment expenditures in total expenditures of communes' budgets (%).

In addition, the article included a point assessment of all diagnostic characteristics that illustrates the financial situation in the studied groups of rural communes against the background of all rural communes in Poland for the years 2018-2022. Individual diagnostic characteristics were compared with the average for all rural communes in the country, which was assumed to be 100 points, and their advantage or disadvantage in all rural communes was assessed accordingly. Then all points were summed up and the average was calculated (Figure 1).

3. Results

There is a clear differentiation between rural communes in Poland in terms of the average value of total income per capita in the years 2018-2022, depending on the level of development of non-agricultural economic activity of individuals. The average value of total income per capita in the years studied is definitely the highest in the group of rural communes with high activity of individuals in the development of non-agricultural economic activity, where it clearly exceeds the average for all rural communes in Poland. On the other hand, in the other two separate groups of rural communes, it is lower and similar and close to the average for all rural communes in the country (Table 1).

In both the case of all rural communes in Poland and in their separate groups, the differentiation of this characteristic between individual communes is in turn small, i.e. its variability is low, and it is the smallest in the group of communes with a low level of development of non-agricultural economic activity of natural persons, i.e. this group of communes is the most homogeneous in this respect (Table 1).

Table 1.
Total revenues of rural commune budgets per capita in Poland in 2018-2022 (PLN)

Specification	Rural communes			
	Total	According to the value of the indicator of the level of development of non-agricultural economic activity of natural persons		
		I	II	III
Average	6.096,5	6.441,0	6.041,6	6.161,8
Variation coefficient V (%)	21,1	21,9	21,4	16,0
Minimum	4.603,2	4.795,0	4.647,5	4.603,2
Maximum	43.452,4	15.971,0	43.452,4	12.190,2

Explanations to the table: I – rural communes in which the level of development of non-agricultural economic activity of individuals is high (the number of business entities of individuals per 100 inhabitants of working age in 2022 was 16.0 and more); II – rural communes in which the level of development of non-agricultural economic activity of individuals is moderate (the number of business entities of individuals per 100 inhabitants of working age in 2022 was from 8.0 to 16.0); III – rural communes in which the level of development of non-agricultural economic activity of individuals is low (the number of business entities of individuals per 100 inhabitants of working age in 2022 was up to 8.0).

Source: Central Statistical Office in Warsaw.

Based on the data in Table 2, it should be noted that there is a clear differentiation between rural communes in Poland in terms of the average value of own income per capita in the years 2018-2022. The average value of the own income of rural commune budgets per capita in the period under review is clearly the highest in the group of rural communes with a high level of development of non-agricultural economic activity of individuals, where it exceeds the average for all rural communes in Poland. In turn, in the remaining two separate groups of rural communes, depending on the level of development of non-agricultural economic activity of individuals, it is lower and similar and close to the average for all rural communes in the country.

Table 2.
Own revenues of rural commune budgets per capita in Poland in 2018-2022 (PLN)

Specification	Rural communes			
	Total	According to the value of the indicator of the level of development of non-agricultural economic activity of natural persons		
		I	II	III
Average	2.245,0	3.308,0	2.128,7	1.934,2
Variation coefficient V (%)	59,7	42,8	60,4	55,2
Minimum	955,2	1.515,5	955,2	997,1
Maximum	38.835,0	12.830,7	38.835,0	8.541,9

Explanations to the table: as for table 1.

Source: Central Statistical Office in Warsaw.

It should be added that the variability of this feature between individual rural communes is large and this applies to all rural communes in Poland, as well as to selected groups of communes. Therefore, the variability of this feature is also large, but it is the smallest in the group of rural communes with a high level of development of non-agricultural economic activity of natural persons (Table 2).

In Poland, there is a differentiation between rural communes in terms of their share of own income in total income in the years 2018-2022. On average, the share of own income in the total income of rural commune budgets in the years studied is clearly the highest in the group of rural communes with a high level of development of non-agricultural economic activity of individuals, where it significantly exceeds the average for all rural communes in the country. On the other hand, it is the lowest in the group of rural communes with a low level of development of non-agricultural economic activity of individuals (Table 3).

Table 3.
Share of own revenues in total revenues of rural commune budgets in Poland in 2018-2022 (%)

Specification	Rural communes			
	Total	According to the value of the indicator of the level of development of non-agricultural economic activity of natural persons		
		I	II	III
Average	36,1	50,0	34,7	30,5
Variation coefficient V (%)	29,2	20,0	26,2	30,5
Minimum	16,9	24,6	17,2	16,9
Maximum	89,4	80,3	89,4	71,4

Explanations to the table: as for table 1.

Source: Central Statistical Office in Warsaw.

The differentiation of this feature between individual rural communes is, in turn, not very large in the group of all rural communes in Poland, as well as in the group of rural communes with a moderate and low level of development of non-agricultural economic activity of individuals. On the other hand, in the group of rural communes with a high level of development of non-agricultural economic activity of individuals, the differentiation of this feature between individual rural communes is small, so its variability is small, i.e., this group of communes is the most homogeneous in this respect (Table 3).

Table 4.
Total expenditure of rural commune budgets per capita in Poland in 2018-2022 (PLN)

Specification	Rural communes			
	Total	According to the value of the indicator of the level of development of non-agricultural economic activity of natural persons		
		I	II	III
Average	5.946,5	6.345,4	5.893,3	5.922,6
Variation coefficient V (%)	22,4	21,1	22,8	18,8
Minimum	4.175,6	4.637,9	4.519,3	4.175,6
Maximum	45.129,0	14.355,1	45.129,0	13.447,7

Explanations to the table: as for table 1.

Source: Central Statistical Office in Warsaw.

There is a clear differentiation between rural communes in Poland in terms of the average value of total expenditure per capita in the years 2018-2022, depending on the level of development of non-agricultural economic activity of individuals. The average value of total expenditure per capita in the years studied is definitely the highest in the group of rural communes with high activity of individuals in the development of non-agricultural economic activity, where it clearly exceeds the average for all rural communes in Poland. On the other hand, in the other two separate groups of rural communes, it is lower and similar and close to the average for all rural communes in the country (Table 4).

Additionally, it should be noted that in the case of all rural communes in the country and in their separate groups, depending on the level of development of non-agricultural economic activity of individuals, the differentiation of this feature between individual communes is small, so its variability is low (Table 4).

The data in Table 5 indicate that there is a clear differentiation between the rural communes of Poland in terms of the average value of investment expenditure per capita in the years 2018-2022. The average value of investment expenditure of rural commune budgets per capita in the period under review is clearly the highest in the group of rural communes with a high level of development of non-agricultural economic activity of individuals, where it exceeds the average for all rural communes in Poland. In turn, in the remaining two separate groups of rural communes, depending on the level of development of non-agricultural economic activity of individuals, it is lower and similar and close to the average for all rural communes in the country.

Table 5.
Investment expenditure of rural commune budgets per capita in Poland in 2018-2022 (PLN)

Specification	Rural communes			
	Total	According to the value of the indicator of the level of development of non-agricultural economic activity of natural persons		
		I	II	III
Average	1.075,4	1.284,2	1.044,4	1.092,8
Variation coefficient V (%)	52,7	43,4	53,9	51,3
Minimum	195,7	195,7	228,2	312,5
Maximum	13.424,6	3.690,2	13.424,6	5.084,8

Explanations to the table: as for table 1.

Source: Central Statistical Office in Warsaw.

In turn, the variability of this feature between individual rural communes is large, and this applies to all rural communes in Poland as well as to selected groups of communes. Therefore, the variability of this feature is also large, but it is the smallest in the group of rural communes with a high level of development of non-agricultural economic activity of individuals (Table 5).

In Poland, there is a difference between rural communes in terms of the share of investment expenditure in total expenditure in the years 2018-2022. On average, the share of investment expenditure in total expenditure of rural commune budgets in the years studied is the highest in the group of rural communes with a high level of development of non-agricultural economic activity of individuals, where it clearly exceeds the average for all rural communes in Poland. On the other hand, in the remaining two separate groups of rural communes, depending on the level of development of non-agricultural economic activity of individuals, it is lower and similar and close to the average for all rural communes in the country (Table 6).

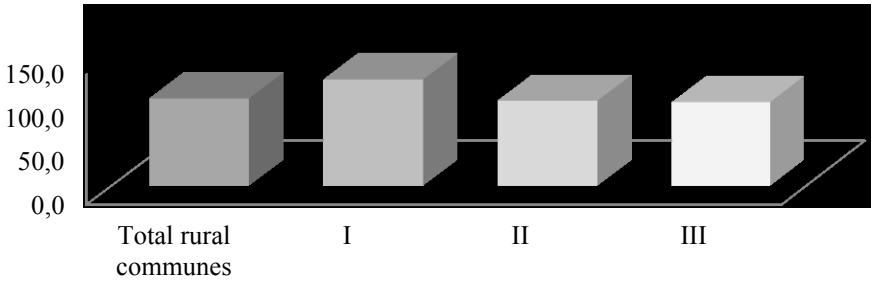
Table 6.
Share of investment expenditure in total expenditure of rural commune budgets in Poland in 2019-2021 (%)

Specification	Rural communes			
	Total	According to the value of the indicator of the level of development of non-agricultural economic activity of natural persons		
		I	II	III
Average	17,6	19,8	17,3	17,9
Variation coefficient V (%)	32,3	30,7	32,3	31,2
Minimum	4,1	4,1	4,6	6,4
Maximum	40,9	38,5	40,9	37,8

Explanations to the table: as for table 1.

Source: Central Statistical Office in Warsaw.

It should be added that the differentiation of this feature between individual rural communes, both in the case of all rural communes in the country and in their separate groups, is not very large and similar, i.e., its variability is average (Table 6).



Explanations for the figure: as for table 1.

Figure 1. Point assessment of the financial situation in the studied groups of rural communes against the background of all rural communes in Poland for the years 2018-2022 (rural communes in Poland = 100.0 points).

Source: Own study.

Figure 1 presents the results of the point assessment of the financial situation in the studied groups of rural communes against the background of all rural communes in Poland for the years 2018-2022. On this basis, it can be seen that there is a large differentiation in this respect between the separate groups of rural communes, depending on the level of development of non-agricultural economic activity of individuals. The financial situation is definitely the best in the

group of rural communes with high activity of individuals in the development of non-agricultural economic activity, where it is also better here, compared to the average for the group of all rural communes in the country. On the other hand, in the remaining two separate groups of rural communes, depending on the level of development of non-agricultural economic activity of individuals, the financial situation is worse and similar, except that it is also slightly worse here than the average for the group of all rural communes in the whole of Poland.

All this allows us to confirm the research hypothesis put forward in the article, which assumes that the financial situation of rural communes in Poland is related to the activity of natural persons in the development of non-agricultural economic activity, and it is clearly the best in the group of units with high activity of natural persons in this respect.

4. Summary and conclusions

The development of non-agricultural economic activity of individuals is particularly important in rural areas because thanks to this they become more attractive, richer, and more diversified, and also perform many important functions, both from the point of view of the economy and society. Hence, this process is supported by local government authorities on the one hand, and on the other hand brings them tangible economic benefits in the form of financial resources inflows to the budget.

Analysis of the collected statistical data showed that:

- rural communes in Poland are differentiated in terms of the average value of total income per capita in the years 2018-2022, depending on the level of development of non-agricultural economic activity of individuals, with this value being definitely the highest in the group of rural communes with high activity of individuals in this area;
- in Poland, there is a differentiation between rural communes in terms of the average value of their own income per capita in the years 2018-2022, with it being clearly the highest in the group of rural communes with a high level of development of non-agricultural economic activity of individuals;
- rural communes in Poland are also diversified in terms of their share of own income in total income in the years 2018-2022. On average, the share of own income in the total income of rural commune budgets in the period under review is definitely the highest in the group of rural communes with a high level of development of non-agricultural economic activity of individuals, while it is the lowest in the group of rural communes with a low level of development of non-agricultural economic activity of individuals;
- there is a difference between rural communes in Poland in terms of the average value of total expenditure per capita in the years 2018-2022, depending on the level of development of non-agricultural economic activity of individuals. The average value of

total expenditure per capita in the years under review is clearly the highest in the group of rural communes with high activity of individuals in the development of non-agricultural economic activity;

- rural communes in Poland are differentiated in terms of the average value of investment expenditure per capita in the years 2018-2022, with it being clearly the highest in the group of rural communes with a high level of development of non-agricultural economic activity of individuals;
- in Poland, there is a differentiation between rural communes in terms of the share of investment expenditure in total expenditure in the years 2018-2022, depending on the level of development of non-agricultural economic activity of individuals, with this share being the highest on average in the group of rural communes with high activity of individuals in this area.

Additionally, the point-based assessment of the financial situation of the surveyed local government units against the background of all rural communes in the country carried out in the article confirmed the research hypothesis, which assumes that the financial situation of rural communes in Poland is related to the activity of natural persons in the development of non-agricultural economic activity, and it is clearly the best in the group of units with high activity of natural persons in this respect.

References

1. Adamczyk, A., Dawidowicz, D. (2016). Wartość informacyjna wskaźników oceny kondycji finansowej jednostek samorządu terytorialnego. *Ekonomiczne Problemy Usług, 25*, pp. 25-36. https://doi.org/10.18276/epu.2016.125-02
2. Bień, W. (2017). Ocena kondycji finansowej gmin województwa małopolskiego w latach 2007-2016. *ZN UE w Katowicach*. *Współczesne Finanse, 1, no. 345*, pp. 45-62.
3. Błachut, B., Cierpiał-Wolan, M., Czudec, A., Kata, R. (2018). *Wydatki inwestycyjne jednostek samorządu terytorialnego a rozwój przedsiębiorczości w regionie Polski południowo-wschodniej*. Rzeszów: Urząd Statystyczny w Rzeszowie.
4. Czudec, A. (2021). Finanse jednostek samorządu terytorialnego w okresie pandemii. *Finanse Komunalne, 5*, pp. 7-18.
5. Dolewka, Z. (2020). *Gospodarowanie zasobami finansowymi w polskim samorządzie terytorialnym*. Łódź/Kraków: Wydawnictwo Uniwersytetu Łódzkiego.
6. Duczkowska-Małysz, K., Duczkowska-Piasecka, M. (2014). Rodzinna przedsiębiorczość na obszarach wiejskich wobec wyzwań globalnych. In: R. Sobiecki (ed.), *Przedsiębiorstwo rodzinne w gospodarce globalnej* (pp. 117-145). Warszawa: SGH.

7. Dylewski, M., Filipiak, B., Gorzałczyńska-Koczkodaj, M. (2011). *Analiza finansowa budżetów jednostek samorządu terytorialnego*. Municipium.
8. Dziemianowicz, R., Kargol-Wasiluk, A., Bołtromiuk, A. (2018). Samodzielność finansowa gmin w Polsce w kontekście koncepcji good governance. *Optimum. Economic Studies, 4(94)*, p. 209. https://doi.org/10.15290/ oes.2018.04.94.16.
9. Filipiak, B. (2011). *Finanse samorządowe. Nowe wyzwania bieżące i perspektywiczne*. Warszawa: Difin.
10. Grzebyk, M., Sołtysiak, M., Stec, M., Zając, D. (2020). *Społeczne, ekonomiczne i środowiskowe uwarunkowania gospodarki finansowej samorządu lokalnego (przykład województwa podkarpackiego)*. Poznań: Bogucki Wydawnictwo Naukowe.
11. Hybel, J. (2000). Makroekonomiczne uwarunkowania rozwoju małych i średnich przedsiębiorstw. In: *Rola małych i średnich przedsiębiorstw w rozwoju obszarów wiejskich* (pp. 21-26). Siedlce: Wydawnictwo Akademii Podlaskiej w Siedlcach.
12. Hybel, J. (2010). Regionalne zróżnicowanie sytuacji finansowej gmin w Polsce w latach 2005-2009. *Zeszyty Naukowe SGGW w Warszawie, Ekonomika i organizacja gospodarki żywnościowej, no. 86*, pp. 29-39.
13. Kamińska, W. (2011). Pozarolnicza aktywność gospodarcza osób fizycznych na obszarach wiejskich w Polsce. In: W. Kamińska, K. Heffner (ed.), *Obszary wiejskie. Wielofunkcyjność. Migracje. Nowe wizje rozwoju.* Studia KPZK PAN, Tom CXXXIII (pp. 103-127). Warszawa.
14. Kata, R., Czudec, A., Zając, D., Zawora, J. (2022). *Gospodarka finansowa jednostek samorządu terytorialnego – wybrane zagadnienia*. Rzeszów: Wydawnictwo Uniwersytetu Rzeszowskiego.
15. Kłodziński, M. (2012). Dywersyfikacja gospodarki ważnym celem polityki wiejskiej. In: M. Drygas, K. Zawalińska (ed.), *Uwarunkowania ekonomiczne polityki rozwoju polskiej wsi i rolnictwa* (pp. 95-115). Warszawa: IRWiR PAN.
16. Kłodziński, M., Rosner, A. (2000). Małe i średnie firmy a rozwój gospodarczy obszarów wiejskich. In: M. Kłodziński, A. Rosner (ed.), *Rozwój przedsiębiorczości na terenach wiejskich wschodniego i zachodniego pogranicza* (pp. 136-147). Warszawa: IRWiR PAN.
17. Kopacz-Wyrwał, I. (2015). Przedsiębiorczość a poziom życia na obszarach wiejskich Polski Wschodniej. *Przedsiębiorczość-Edukacja, vol. 11*, pp. 82-97.
18. Kopyściański, T., Rólczyński, T. (2014). Analiza wskaźników opisujących sytuację finansową powiatów w województwie dolnośląskim w latach 2006-2012. *Studia Ekonomiczne, 206*, pp. 61-73.
19. Kotowska, E. (2016). Przesłanki racjonalnej polityki budżetowej w jednostkach samorządu terytorialnego. In: A. Gołębiowska, P.B. Zientarski (ed.), *Funkcjonowanie samorządu terytorialnego – uwarunkowania prawne i społeczne*. Warszawa: Kancelaria Senatu RP.
20. Kowalska, I., Możyłowski, P., Śmietanka, T. (ed.) (2019). *Funkcjonowanie jednostek samorządu terytorialnego w wymiarze finansowo-prawnym*. Radom: Instytut Naukowo-Wydawniczy Spatium.

21. Kulawiak, A. (2022). Pozarolnicza działalność gospodarcza a rozwój społeczno-gospodarczy gmin wiejskich województwa łódzkiego. *Przedsiębiorczość-Edukacja, 18(1)*, pp. 64-78. https://doi.org/10.24917/20833296.181.6
22. Natrini, N.D., Taufiq Ritonga, I. (2017). Design and Analysis of Financial Condition Local Government Java and Bali (2013-2014). *SHS Web of Conferences, 34: 03003* https://doi.org/10.1051/shsconf/20173403003
23. Ociepa-Kicińska, E., Gorzałczyńska-Koczkodaj, M., Brzozowska, K., Pluskota, P. (2022). Ocena kondycji finansowej jednostek samorządu terytorialnego w obliczu pandemii COVID-19 na przykładzie województw samorządowych w Polsce. *Rozwój Regionalny i Polityka Regionalna, 59*, pp. 149-165.
24. Ossowska, L., Ziemińska, A. (2010). Kondycja finansowa gmin wiejskich i miejsko-wiejskich województwa pomorskiego. *Journal of Agribusiness and Rural Development, no. 4(18)*, pp. 73-85.
25. Rosner, A. (2012). *Zmiany rozkładu przestrzennego zaludnienia obszarów wiejskich. Wiejskie obszary zmniejszające zaludnienie i koncentrujące ludność wiejską*. Warszawa: IRWiR PAN.
26. Sierak, J. (2017). Regionalne zróżnicowanie wielkości i dynamiki dochodów gmin i miast na prawach powiatu – analiza wskaźnikowa dla lat 2000-2014. *Finanse Komunalne, no. 1-2*, p. 77.
27. Standar, A. (2017). Ocena kondycji finansowej gmin oraz jej wybranych uwarunkowań na przykładzie województwa wielkopolskiego przy wykorzystaniu metody TOPSIS. *Wieś i Rolnictwo, no. 2(175)*, pp. 69-92.
28. Stanny, M., Strzelczyk, W. (2018). *Kondycja finansowa samorządów lokalnych a rozwój społeczno-gospodarczy obszarów wiejskich. Ujęcie przestrzenne*. Warszawa: Scholar.
29. Świrska, A. (2016). Czynniki determinujące efektywne zarządzanie finansami samorządowymi (na przykładzie gmin powiatu siedleckiego). *Polityki Europejskie, Finanse i Marketing, 16(65)*, pp. 88-99.
30. Wiśniewski, M. (2011). Wyznaczniki sytuacji finansowej gminy. Ocena istotności za pomocą analizy skupień. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu. Nauki o Finansach, 9(215)*, pp. 110-119.
31. Wójtowicz, K. (2018). Znaczenie wybranych czynników ekonomiczno-społecznych dla kształtowania stabilności fiskalnej gmin miejskich w Polsce. *Acta Universitatis Lodziensis. Folia Oeconomica, vol. 334(2)*, pp. 213-234.
32. Zając, D. (2014). Znaczenie pozarolniczej działalności gospodarczej rolników w procesie rozwoju wielofunkcyjności rolnictwa i obszarów wiejskich. *Prace Naukowe Wydziału Ekonomii Uniwersytetu Rzeszowskiego, Seria: Monografie i Opracowania, no. 17.* Rzeszów: Wydawnictwo Uniwersytetu Rzeszowskiego.
33. Zarębski, P. (2015). Typy obszarów wiejskich w Polsce ze względu na poziom rozwoju społeczno-gospodarczego i dynamikę przedsiębiorstw. *Wieś i Rolnictwo, 3(168)*, pp. 63-77.

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THE FINANCIAL SITUATION OF LOCAL GOVERNMENT ENTITIES IN THE LOWER SILESIAN AND PODKARPACKIE VOIVODESHIP IN THE BACKGROUND OF THE COUNTRY

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Purpose: The aim of the article is to identify and assess the financial situation of local government units in the Lower Silesian and Podkarpackie voivodeships compared to the country.
Design/methodology/approach: The article identifies and assesses the financial situation of local government units in Lower Silesian and Podkarpackie voivodeships compared to the country. The empirical material of the article concerns both the entire country and all local government units in the Lower Silesian and Podkarpackie voivodeships. The numerical data come from the Local Data Bank of the Central Statistical Office Local Data Bank in Warsaw and are for the years 2018-2022. The collected and organised empirical material was developed in descriptive, tabular, and graphic form, using the method of comparative analysis. The article also uses basic measures of descriptive statistics, i.e. mean, coefficient of variation, and minimum and maximum values. Additionally, a point assessment was also performed of all diagnostic characteristics illustrating the financial situation of local government units in the Lower Silesian and Podkarpackie voivodeships against the background of the entire country, which is a new approach to the research problem discussed in the article.
Findings: The analysis of the collected and processed statistical data confirmed the research hypothesis put forward in the article, which assumes that local government units in Poland are diverse in terms of their financial situation and due to the fact of a higher level of economic development, units in the Lower Silesian Voivodeship are characterised by a better financial situation compared to the Podkarpackie Voivodeship.
Originality/value: The originality of the work lies in the author's approach to the analysis of the research issues undertaken. The financial situation of the surveyed local government units compared to the country was assessed on a point-by-point basis. The work is addressed primarily to local government officials in the studied voivodeships, responsible for public local government finances, as well as for the conditions, possibilities and directions of further socio-economic development of these regions.
Keywords: local government units, financial situation, Lower Silesian and Podkarpackie voivodeships, Poland.
Category of the paper: research paper.

1. Introduction

Local government is one of the most important public sector institutions in every democratic country, because it is the most direct form of making and implementing important decisions by the local government community formed by all the inhabitants of the local environment or region. This is about deciding on the most important issues in the public sphere that concern all residents, such as: the availability and quality of education, health care, environmental protection, and municipal infrastructure (roads, waterworks, sewage systems, sports and recreational facilities). The most important document determining the place of local self-government in the member states of the Council of Europe is the European Charter of Local Self-Government (Kata, Czudec, Zając, Zawora, 2022).

The local government is a key institution responsible for the implementation of many tasks aimed at meeting the needs of the primary importance of residents, as well as creating social and economic development in the regional and local system. The effectiveness of the implementation of tasks by local government units is largely dependent on effective financial management, and their implementation is guaranteed by adequate economic potential. Therefore, the quality of the local government finance system is important in this respect. The financial system of local government consists of a set of rules, procedures, and legal solutions that regulate the mechanism of functioning of its authorities and administration in the financial sphere. Documents describing the financial system of local governments create the basis for the local government's economy and are tools used in conducting financial policy by its bodies. The local government finance system is a set of rules, institutions, and procedures relating to the collection and expenditure of financial resources of local government units (Strzelecki, 2008; Dolewka, 2020; Grzebyk, Sołtysiak, Stec, Zając, 2020; Kata, Czudec, Zając, Zawora, 2022).

Local government finances constitute an important element of public finances and can be defined in broader and narrower terms, but in a broader sense, they are the processes related to the collection and expenditure of financial resources included in the financial plan of a given local government unit. However, in a narrower sense, we consider them according to the territorial division of the country, i.e. we distinguish between local and regional finances (Owsiak, 1999; Kosikowski, 2001; Filipiak, 2011; Dolewka, 2020).

The financial management of local government units is a complex process, carried out with respect to legislative requirements within the local government budget. Ensuring the efficient and proper operation of this specific economy, which consists primarily of cash and property resources, requires strict compliance with many legal acts, standards, and budgetary principles. As part of the financial management of local government units, various public tasks and financial operations are carried out relating to individual sections of public finances, and various

legal and financial methods and instruments are used (Chojna-Duch, 2003; Kosek-Wojnar, Surówka, 2007; Sołtyk, 2017; Sołtysiak, 2017; Sołtysiak, Suraj, 2018).

Financial management in local government therefore includes all activities related to planning, organization, implementation, control and supervision in the field of collecting and spending budget funds. The financial policy of local government means, in turn, the conscious and purposeful activity of its bodies, consisting in selecting socio-economic goals and tasks and achieving them through the selection of means and implementation methods (Dolewka, 2020).

The development of a local government unit is the objective of its operation. This development should be understood as positive changes of quantitative, qualitative, and structural nature. The way to achieve this is investment activity, traditionally understood as a beneficial change in assets or, nowadays, as the use of an economic resource that has the specific property of generating the so-called added value. According to the concept of public governance, added value is public value for the residents of a local government community. In general, investment involvement also includes the activities of private entities as a result of public incentives (Dolewka, 2020).

Management and financial management in local government are two sides of the process of providing public services. Financial management concerns the transformation of limited financial resources into the supply of services that meet the social needs of residents. These services are direct effects of this process that trigger derivative effects. It is worth noting that in the field of economic sciences, management means the process of making choices (making decisions), determined on the one hand by unlimited human needs and on the other by limited opportunities (economic resources), according to the criterion of optimising the benefits associated with these decisions. In turn, financial management in local government is a process involving the authorities taking actions and decisions aimed at maximising social and economic effects, in accordance with the adopted goals (Rudzka-Lorentz, Sierak, 2006; Wojciechowski, 2012; Dolewka, 2020).

The financial management of the public sector units, including the local government units, should support rational spending of public funds and making appropriate decisions about the management of these funds. The basic goal in the financial management process should be to maximise the benefits from available resources and minimise losses and risks related to the activities undertaken, which especially applies to development projects, where benefits and costs are usually spread over time. Therefore, financial management should focus on: - shaping the amount and structure of budget revenues and determining the methods and sources of their acquisition, - shaping the capital and property structure that guarantees maintaining economic and financial balance, - allocating available financial resources, - shaping the size and structure of expenses in connection with ongoing and investment activities, - influencing the level of risk accompanying decisions made, - monitoring and forecasting the financial and property situation, - ongoing assessment of the financial and property situation of the local government enabling the assessment of compliance of the course of current, investment and financial

activities with the adopted assumptions, - assessment the impact of external conditions on investment and financial decisions, - formulating conclusions and recommendations regarding running a business, - setting a financing strategy. A properly managed entity should, in the long term, develop the so-called "good indicators", i.e. those that prove its development. Particularly noteworthy is the concept of the financial situation of a local government unit, interpreted as the ability of the local government to balance recurring expenditure needs with recurring sources of income, while simultaneously implementing tasks resulting from legal provisions that are intended to further increase income and maximise public utility for its residents (Mrówczyńska-Kamińska, Kucharczyk, Średzińska, 2011; Adamczyk, Dawidowicz, 2016; Kowalska, Możyłowski, Śmietanka, 2019; Kata, Czudec, Zając, Zawora, 2022; Ociepa-Kicińska, Gorzałczyńska-Koczkodaj, Brzozowska, Pluskota, 2022).

The financial situation of a local government means the state of its economy in financial terms. In other words, it is an image of the financial condition that is subject to assessment (financial standing). Financial assessment may be carried out by an internal entity (local government financial services subordinated to the treasurer, internal auditors) or external entities with supervisory and control powers (regional chambers of audit, Supreme Audit Office) or specialized market agencies (analyses, reports, preparing ratings). The results of financial analyses pose certain challenges for local government authorities because they stimulate thinking based on economic logic and contribute to deepening the assessment of the economy and financial policy. It should be added that the assessment of financial condition is a form of diagnosis that allows the improvement of the decision-making process towards improving the efficiency of managing property resources (Sierak, 2017; Standar, 2017; Dolewka, 2020).

When defining the financial situation of a local government unit, the following are most often emphasized: the possibility of financing services on a continuous basis, the comprehensiveness of healthy finances, the ability to repay liabilities, as well as maintaining the current level of services while maintaining resistance to the risk of changes occurring over time. It seems that the most accurate interpretation is the financial situation of a local government unit, referring to its ability to timely meet its financial obligations and to maintain services provided to the local community (Filipiak, 2009, 2011; Dylewski, Filipiak, Gorzałczyńska-Koczkodaj, 2011; Wiśniewski, 2011; Kopyściański, Rólczyński, 2014; Zawora, 2015; Adamczyk, Dawidowicz, 2016; Kotowska, 2016; Natrini, Taufiq Ritonga, 2017; Ociepa-Kicińska, Gorzałczyńska-Koczkodaj, Brzozowska, Pluskota, 2022).

The financial situation of a local government unit is its financial condition in a specific period of time, resulting from its income and its structure, expenses and their structure, the degree of use of repayable funds, activity and effectiveness in obtaining extra-budgetary funds, as well as the efficiency of management of financial and material resources. Local authorities should care about the good financial situation of a given territorial unit, as it is an element of its competitiveness. In addition, it is evidenced, among other things,

the ability to perform tasks, achieve budget balance, as well as increase assets and to implement and satisfy the needs of residents. Among a number of various conditions shaping the financial management of a local government unit, including its financial situation, the most general categories include exogenous, endogenous, and mixed conditions. Moreover, certain common categories can be distinguished, which include social, economic, environmental and spatial conditions, as well as institutional, legal, and political conditions. The catalogue of such factors is sometimes expanded to include events whose effects cannot be predicted and which may fundamentally change the economic situation and operating conditions of local government units. This event in 2020 was the emergence of the coronavirus pandemic. It should be added that the analysis of the financial situation of a local government unit provides information about its current and future property and financial situation, and also allows one to determine its possibilities and development prospects (Ossowska, Ziemińska, 2010; Zawora, 2015; Świrska, 2016; Bień, 2017; Standar, 2017; Stanny, Strzelczyk, 2018; Wójtowicz, 2018; Czudec, 2021).

2. Research aim, empirical material, and research methods

The aim of the article is to identify and assess the financial situation of local government units in the Lower Silesian and Podkarpackie voivodeships compared to the country.

The article presents a research hypothesis that assumes that local government units in Poland are diverse in terms of their financial situation, and due to the higher level of economic development, units in the Lower Silesian Voivodeship have a better financial situation compared to the Podkarpackie Voivodeship.

The empirical material of the article concerns both the entire country and all local government units in the Lower Silesian and Podkarpackie voivodeships. The numerical data comes from the Local Data Bank of the Central Statistical Office in Warsaw and concerns the years 2018-2022. The collected and organised empirical material was developed in descriptive, tabular, and graphic form, using the method of comparative analysis. The article also uses basic measures of descriptive statistics, i.e. mean, coefficient of variation, and minimum and maximum values.

To identify and assess the financial situation of local government units in Lower Silesian and Podkarpackie Voivodeships compared to the country, the following diagnostic features illustrating it in the years 2018-2022 were analysed:

- total revenues of the budgets of local government units per capita (PLN),
- own revenues of the budgets of local government units per capita (PLN),
- share of own revenues in the total revenues of the budgets of local government units (%),
- total budget expenditure of local government units per capita (PLN),

- investment expenditure of local government budgets per capita (PLN),
- share of investment expenditure in total budget expenditure of local government units (%).

In addition, the article provides a point assessment of all diagnostic characteristics that illustrates the financial situation of local government units in the Lower Silesian and Podkarpackie Voivodeships against the background of the entire country for the years 2018-2022. Individual diagnostic characteristics were compared with the average for the country, which was taken as 100 points, and their advantage or underweight was assessed accordingly in all local government units of the studied voivodeships. Then, all points were summarised and the average was calculated (Figure 1). It should be emphasised that this is a new approach to the research problem discussed in the article.

3. Results

The Lower Silesian Voivodeship is located in the southwest part of Poland and borders with Germany and the Czech Republic. Its area is 19,947 km^2 and the number of inhabitants is 2,888,033 people. Therefore, the population density in the Lower Silesian Voivodeship is 144.8 people per 1 km^2. However, the value of GDP per capita is PLN 90,980 (for the whole of Poland, this value is PLN 81,093), i.e., it is a region characterised by one of the highest levels of economic development in the country. The Podkarpackie Voivodeship is located in the southeast part of Poland and borders with Ukraine and Slovakia. Its area is 17,845 km^2 and the number of inhabitants is 2,079,098 people. Therefore, the population density in this Voivodeship is 116.5 people per 1 km^2. However, the GDP per capita is PLN 55,125 (for the whole of Poland this value is PLN 81,093)[1], so it is a region characterised by one of the lowest levels of economic development in the country. Additionally, it should be emphasised that both voivodeships covered by the research are border regions, which should certainly be treated as an advantage, creating opportunities for further socio-economic development and thus also improving the financial situation of local government units located in their area.

The revenue system of local government units should ensure their fiscal stability, i.e., a relatively stable state in which local government authorities are able to ensure a range of appropriate quality public services, appropriate to the needs of the territorial community, and are also able to stimulate socio-economic development. In turn, long-term fiscal stability creates the basis for the ability to provide public services in a continuous and effective manner,

[1] The numerical data comes from the Local Data Bank of the Central Statistical Office in Warsaw and concerns 2022.

as well as for the settlement of related financial obligations (Wójtowicz, 2014a, 2014b, 2018; Poniatowicz, 2016).

Table 1.
Total income of local government unit budgets per capita in the Lower Silesian and Podkarpackie voivodeships compared to the country in 2018-2022 (PLN)

Specification	Local government units *			
	I	II	III	IV
Poland				
	7.586,0	5.783,7	5.825,9	6.096,5
Coefficient of variation V (%)	15,2	23,2	14,7	21,1
Minimum (PLN)	6.015,9	4.229,8	4.399,8	4.603,2
Maximum (PLN)	12.746,6	18.056,3	12.729,6	43.452,4
Lower Silesia voivodeship				
Mean	7.261,7	6.034,7	5.884,7	6.381,0
Coefficient of variation V (%)	8,3	30,3	16,7	21,4
Minimum (PLN)	6.820,6	4.229,8	4.742,2	4.952,3
Maximum (PLN)	8.128,5	11.848,3	10.740,1	12.154,5
Podkarpackie voivodeship				
Mean	7.933,1	5.610,7	5.583,8	5.875,0
Coefficient of variation V (%)	9,8	7,6	8,7	15,2
Minimum (PLN)	7.233,0	4.955,3	4.787,3	4.712,4
Maximum (PLN)	9.007,5	6.390,7	7.546,6	10.237,4

Explanations for the table: * I – cities with county rights; II – urban communes; III – urban-rural communes; IV – rural communes.

Source: Central Statistical Office in Warsaw.

Similarly to the entire country, also in the voivodeships covered by the research, the average value of total budget revenues per capita in 2018-2022 varies between separate groups of local government units. In the period under study, the average value of total budget revenues per capita is clearly the highest in the group of cities with county rights, especially in the Podkarpackie Voivodeship, and then in the group of rural communes, especially in the Lower Silesian Voivodeship (Table 1).

Additionally, it should be noted that the differences in this feature between individual local government units are rather small or small in all their groups in Poland and in the studied voivodeships, so its variability is small, which proves that they are relatively homogeneous in terms of in this respect (Table 1).

Own revenues constitute a strategic element in the financial system of local government units, both from the point of view of the scope of financial independence, as well as in the context of the possibility of applying for financial resources from the European Union or from other supplementary sources of financing their activities, functioning and development. In addition, a larger share of own revenues in total budget revenues allows local governments to use financial resources more freely and creates the opportunity for them to conduct their own, undisturbed economy and financial policy aimed at improving the socio-economic situation and further development (Gołaszewska-Kaczan, 2005; Sobczyk, 2010; Sierak, 2015; Poniatowicz, 2016; Dziemianowicz, Kargol-Wasiluk, Bołtromiuk, 2018; Czudec, 2021; Szołno-Koguc, 2021).

Table 2.
Own income of the budgets of local government units per capita in the Lower Silesian and Podkarpackie voivodeships compared to the country in 2018-2022 (PLN)

Specification	Local government units *			
	I	II	III	IV
Poland				
Mean	3.905,0	3.012,5	2.430,9	2.245,0
Coefficient of variation V (%)	26,3	39,1	37,3	59,7
Minimum (PLN)	2.546,0	1.857,5	1.077,5	955,2
Maximum (PLN)	7.962,2	13.736,1	9.480,0	38.835,0
Lower Silesia voivodeship				
Mean	3.922,9	3.342,8	2.693,9	3.066,5
Coefficient of variation V (%)	26,5	42,1	38,4	45,3
Minimum (PLN)	3.231,3	1.857,5	1.717,4	1.562,8
Maximum (PLN)	5.470,1	7.373,4	8.140,3	9.073,3
Podkarpackie voivodeship				
Mean	3.317,7	2.791,4	1.808,2	1.844,2
Coefficient of variation V (%)	17,0	16,9	20,9	45,8
Minimum (PLN)	2.790,0	2.011,5	1.272,6	997,1
Maximum (PLN)	3.878,6	3.722,2	2.850,5	6.500,1

Explanations for the table: * I – cities with county rights; II – urban communes; III – urban-rural communes; IV – rural communes.

Source: Central Statistical Office in Warsaw.

Both in the entire country and in the surveyed voivodeships, the average value of own income per capita in 2018-2022 varies between separate groups of local government units. It should be noted that it is definitely the highest in the group of cities with county rights, and this also applies to the group of urban communes, especially in the Lower Silesian Voivodeship (Table 2).

In turn, the differentiation of this feature between individual local government units is rather small in the case of the group of cities with county rights, especially in the Podkarpackie Voivodeship, where it is similar also in the group of urban and urban-rural communes, i.e. these units are relatively homogeneous in this respect. However, in the case of the group of urban, urban-rural and rural communes in Poland and in the Lower Silesian Voivodeship, as well as in the group of rural communes in the Podkarpackie Voivodeship, the characteristic differences in the analysed between individual local government units are quite large (Table 2).

Similarly to the entire country, also in the voivodeships covered by the research, the share of own income in total income in 2018-2022 varies between separate groups of local government units. In the analysed years, the share of own income in total income is clearly higher in the group of urban communes and in the group of cities with county rights, especially in the Lower Silesian Voivodeship (Table 3).

Furthermore, the differences in this feature between individual local government units are rather small or small in all their groups in Poland and in the studied voivodeships, and especially in the group of urban communes and in the group of cities with poviat rights, proving that these units are relatively homogeneous in this respect (Table 3).

Table 3.
Share of own income in the total income of the budgets of local government units in the Lower Silesian and Podkarpackie voivodeships compared to the country in 2018-2022 (%)

Specification	Local government units *			
	I	II	III	IV
Poland				
Mean	51,1	51,3	41,3	36,1
Coefficient of variation V (%)	15,4	14,7	24,4	29,2
Minimum (PLN)	35,2	31,4	19,0	16,9
Maximum (PLN)	71,3	77,9	79,6	89,4
Lower Silesia voivodeship				
Mean	53,5	54,2	45,1	46,7
Coefficient of variation V (%)	17,7	14,2	22,1	21,9
Minimum (PLN)	47,4	40,8	26,7	29,9
Maximum (PLN)	67,3	67,9	75,8	74,6
Podkarpackie voivodeship				
Mean	41,7	49,8	32,6	30,9
Coefficient of variation V (%)	11,8	14,6	23,0	28,5
Minimum (PLN)	37,1	32,3	21,1	16,9
Maximum (PLN)	48,6	58,7	53,8	67,2

Explanations for the table: * I – cities with county rights; II – urban communes; III – urban-rural communes; IV – rural communes.

Source: Central Statistical Office in Warsaw.

Expenditures of local government units include the transfer of public financial resources for the implementation of their tasks, i.e. to meet the collective needs of local and regional communities in the field of public utility. Therefore, the level and structure of these expenses are fully reflected in the directions of their activities. It should be added that the expenditure of the local government sector is constantly growing, and this tendency was observed by Wagner - in the law of constant increase in public expenditure, also called the law of constantly growing financial needs. In turn, the reasons for the need to increase the expenditure of local government units include: political, social and sociological, and economic, with many of them having a complex and multifaceted nature (Kańduła, 2010; Jastrzębska, 2012).

Both in the entire country and in the surveyed voivodeships, the average value of total budget expenditure per capita in 2018-2022 varies between separate groups of local government units. In the period under study, the average value of total budget expenditure per capita is clearly the highest in the group of cities with county rights, especially in the Podkarpackie Voivodeship, and then in the group of rural communes, especially in the Lower Silesian Voivodeship (Table 4).

The variation in this characteristic between individual local government units is, in turn, rather small or small in all their groups in Poland and in the studied voivodeships, so its variability is small, which shows that they are relatively homogeneous in this respect (Table 4).

Table 4.
Total budget expenditure of local government units per capita in the Lower Silesian and Podkarpackie voivodeships compared to the country in 2018-2022 (PLN)

Specification	Local government units*			
	I	II	III	IV
Poland				
Mean	7.718,3	5.742,2	5.766,8	5.946,5
Coefficient of variation V (%)	16,5	21,9	15,2	22,4
Minimum (PLN)	6.068,4	4.051,3	4.307,6	4.175,6
Maximum (PLN)	14.291,5	18.007,2	12.062,8	45.129,0
Lower Silesia voivodeship				
Mean	7.363,4	5.900,0	5.896,4	6.202,4
Coefficient of variation V (%)	9,1	29,0	18,4	21,2
Minimum (PLN)	6.900,5	4.051,3	4.542,0	4.611,6
Maximum (PLN)	8.321,0	11.723,2	11.338,9	11.435,8
Podkarpackie voivodeship				
Mean	8.031,7	5.672,7	5.519,3	5.708,5
Coefficient of variation V (%)	12,5	8,9	8,5	15,4
Minimum (PLN)	7.216,2	4.813,9	4.609,9	4.592,6
Maximum (PLN)	9.329,3	6.765,4	6.967,5	10.051,8

Explanations for the table: * I – cities with county rights; II – urban communes; III – urban-rural communes; IV – rural communes.

Source: Central Statistical Office in Warsaw.

The wealth of local government units clearly affects their investment opportunities, and units with higher budget income per capita, including their own income, usually also have greater investment potential. In turn, the implementation of investments by local government units is one of their most important tasks, because it meets the needs of local communities and contributes to their further development. Investment expenditures in the economy and financial policy of local government units, apart from their own income, are therefore an important factor determining their development prospects (Filipiak, 2011; Błachut, Cierpiał-Wolan, Czudec, Kata, 2018).

Similarly to the whole country, also in the voivodeships covered by the research, the average value of investment expenditure per capita in 2018-2022 varies between separate groups of local government units. In the years examined, the average value of investment expenditure per capita is definitely the highest in the group of cities with county rights in Poland and in the Podkarpackie Voivodeship, as well as in the group of rural communes in the Lower Silesian Voivodeship (Table 5).

Additionally, it should be noted that the differences in this feature between individual local government units are quite large and large in all their groups in Poland and in the studied voivodeships (Table 5).

Both in the entire country and in the surveyed voivodeships, the share of investment expenditure in total expenditure in 2018-2022 varies slightly between separate groups of local government units. In the period under study, the share of investment expenditure in total expenditure is the lowest in the group of cities with county rights, and this applies both to Poland and both voivodeships covered by the research (Table 6).

Table 5.
Investment expenditure of the budgets of local government units per capita in the Lower Silesian and Podkarpackie voivodeships compared to the country in 2018-2022 (PLN)

Specification	Local government units*			
	I	II	III	IV
Poland				
Mean	1.268,3	965,8	976,1	1.075,4
Coefficient of variation V (%)	66,4	57,2	45,6	52,7
Minimum (PLN)	431,4	362,5	166,7	195,7
Maximum (PLN)	7.281,4	5.381,3	3.934,3	13.424,6
Lower Silesia voivodeship				
Mean	1.109,1	1.099,8	1.165,6	1.215,3
Coefficient of variation V (%)	31,1	67,5	51,7	56,6
Minimum (PLN)	766,4	369,9	477,6	280,1
Maximum (PLN)	1.422,0	3.939,9	3.901,4	3.435,0
Podkarpackie voivodeship				
Mean	1.212,8	998,1	988,0	1.043,1
Coefficient of variation V (%)	55,7	34,1	32,4	47,6
Minimum (PLN)	431,4	542,5	432,0	269,0
Maximum (PLN)	2.009,8	1.593,4	1.833,4	3.690,2

Explanations for the table: * I – cities with county rights; II – urban communes; III – urban-rural communes; IV – rural communes.

Source: Central Statistical Office in Warsaw.

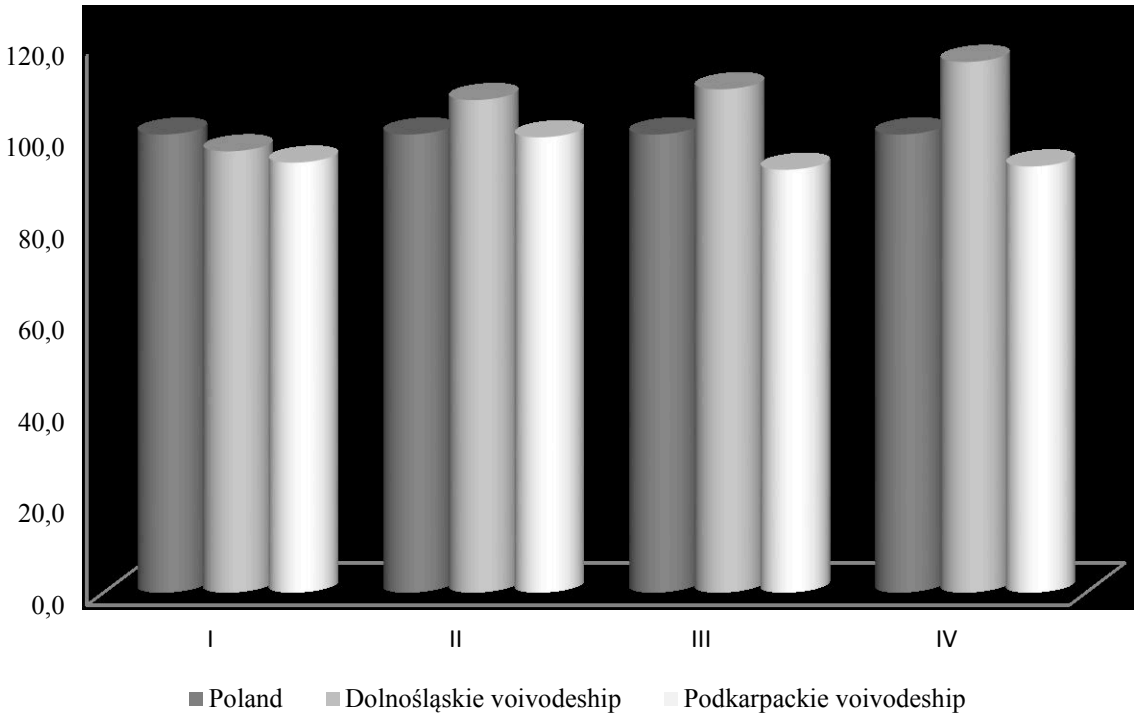
The differences in this feature between individual local government units are quite large in all their groups in Poland and in the studied voivodeships, and especially in the group of cities with county rights in the Podkarpackie Voivodeship (Table 6).

Table 6.
Share of investment expenditure in total budget expenditure of local government units in the Lower Silesian and Podkarpackie voivodeships compared to the country in 2018-2022 (%)

Specification	Local government units *			
	I	II	III	IV
Poland				
Mean	15,8	16,2	16,5	17,6
Coefficient of variation V (%)	36,2	32,0	33,4	32,3
Minimum (PLN)	5,9	6,6	3,6	4,1
Maximum (PLN)	50,9	33,7	45,2	40,9
Lower Silesia voivodeship				
Mean	14,9	17,4	19,2	18,8
Coefficient of variation V (%)	25,7	34,6	34,5	37,8
Minimum (PLN)	11,1	9,1	6,9	5,2
Maximum (PLN)	19,4	33,6	45,2	40,9
Podkarpackie voivodeship				
Mean	14,6	17,4	17,8	17,8
Coefficient of variation V (%)	45,8	27,6	29,1	33,7
Minimum (PLN)	5,9	10,2	8,6	5,0
Maximum (PLN)	21,5	24,4	31,9	38,5

Explanations for the table: * I – cities with county rights; II – urban communes; III – urban-rural communes; IV – rural communes.

Source: Central Statistical Office in Warsaw.



Explanations: I – cities with county rights; II – urban communes; III – urban-rural communes; IV – rural communes.

Figure 1. Point assessment of the financial situation of local government units in the Lower Silesian and Podkarpackie voivodeships compared to the entire country for the years 2018-2022 (Poland = 100.0 points).

Source: Own study.

Figure 1 presents the results of the point assessment on the financial situation of local government units in the Lower Silesian and Podkarpackie Voivodeships compared to the entire country for the years 2018-2022. It should be noted that in the case of all groups of local government units identified in the article and analysed, i.e. cities with poviat rights and urban, urban-rural and rural communes, the financial situation is better in the Lower Silesian Voivodeship. It should be added that in the groups of communes without cities with county rights in this voivodeship, their financial situation is even better compared to the average for the entire country, and this especially applies to the group of rural communes. However, in the Podkarpackie Voivodeship, all groups of local government units are characterised by a slightly worse financial situation compared to their counterparts in the Lower Silesian Voivodeship and in the country.

All this confirms the research hypothesis put forward in the article, which assumes that local government units in Poland are diversified in terms of their financial situation, and due to the higher level of economic development, units in the Lower Silesian Voivodeship have a better financial situation compared to the Lower Silesian Voivodeship. Podkarpackie.

4. Summary and conclusions

Local government units perform very important tasks and functions, both from the point of view of society and the economy, primarily by conducting an effective and efficient socioeconomic development policy, which is based on responsible and rational financial management.

The analysis of the collected statistical data carried out in the article allows the following conclusions to be formulated:

- separate groups of local government units in Poland and in the analysed Lower Silesian and Podkarpackie voivodeships are diverse in terms of all analyzed diagnostic features illustrating their financial situation in 2018-2022,
- the average value of total budget revenues and expenses per capita in the years 2018-2022 is clearly the highest in the group of cities with county rights, especially in the Podkarpackie Voivodeship, and then in the group of rural communes, especially in the Lower Silesian Voivodeship,
- the average value of own income per capita in the years 2018-2022 is definitely the highest in the group of cities with county rights, and this also applies to the group of urban communes, especially in the Lower Silesian Voivodeship,
- the share of own revenues in total revenues in the years 2018-2022 is clearly higher in the group of urban communes and in the group of cities with county rights, and this especially applies to the Lower Silesian Voivodeship,
- the average value of investment expenditure per capita in the years 2018-2022 is definitely the highest in the group of cities with county rights in Poland and in the Podkarpackie Voivodeship, as well as in the group of rural communes in the Lower Silesian Voivodeship,
- the share of investment expenditure in total expenditure in the years 2018-2022 is the lowest in the group of cities with county rights, and this applies to both the whole of Poland and both voivodeships covered by the research.

Moreover, the analysis of statistical data allows us to confirm the research hypothesis, which assumes that local government units in Poland are diversified in terms of their financial situation, and due to the higher level of economic development, units in the Lower Silesian Voivodeship have a better financial situation compared to the Lower Silesian Voivodeship. Podkarpackie.

It should be added that the presented results and conclusions from the research and analyses of collected statistical data provide important and up-to-date knowledge that may be useful primarily for local government officials in the surveyed voivodeships, responsible for public local government finances, as well as for the conditions, possibilities and directions of further development. Socioeconomic development of these regions, which justifies the need to continue similar research and analyses, mainly to verify and update them.

References

1. Adamczyk, A., Dawidowicz, D. (2016). Wartość informacyjna wskaźników oceny kondycji finansowej jednostek samorządu terytorialnego. *Ekonomiczne Problemy Usług, 25*, pp. 25-36. https://doi.org/10.18276/epu.2016.125-02
2. Bień, W. (2017). Ocena kondycji finansowej gmin województwa małopolskiego w latach 2007-2016. *ZN UE w Katowicach*. *Współczesne Finanse, 1, no. 345*, pp. 45-62.
3. Błachut, B., Cierpiał-Wolan, M., Czudec, A., Kata, R. (2018). *Wydatki inwestycyjne jednostek samorządu terytorialnego a rozwój przedsiębiorczości w regionie Polski południowo-wschodniej*. Rzeszów: Urząd Statystyczny w Rzeszowie.
4. Chojna-Duch, E. (2003). *Polskie prawo finansowe. Finanse publiczne*. Warszawa: Lexis Nexis.
5. Czudec, A. (2021). Finanse jednostek samorządu terytorialnego w okresie pandemii. *Finanse Komunalne, 5*, pp. 7-18.
6. Dolewka, Z. (2020). *Gospodarowanie zasobami finansowymi w polskim samorządzie terytorialnym*. Łódź-Kraków: Wydawnictwo Uniwersytetu Łódzkiego.
7. Dylewski, M., Filipiak, B., Gorzałczyńska-Koczkodaj, M. (2011). *Analiza finansowa budżetów jednostek samorządu terytorialnego*. Municipium.
8. Dziemianowicz, R., Kargol-Wasiluk, A., Bołtromiuk, A. (2018). Samodzielność finansowa gmin w Polsce w kontekście koncepcji good governance. *Optimum. Economic Studies, 4(94)*, p. 209. https://doi.org/10.15290/ oes.2018.04.94.16.
9. Filipiak, B. (2011). *Finanse samorządowe. Nowe wyzwania bieżące i perspektywiczne*. Warszawa: Difin.
10. Filipiak, B. (ed.) (2009). *Metodyka kompleksowej oceny gospodarki finansowej jednostki samorządu terytorialnego*. Warszawa: Difin.
11. Gołaszewska-Kaczan, U. (2005). Partnerstwo publiczno-prywatne a atrakcyjność regionu. In: A. Kopczyk, M. Proniewski (ed.), *Atrakcyjność inwestycyjna regionu* (pp. 545-552). Białystok: Wyższa Szkoła Finansów i Zarządzania.
12. Grzebyk, M., Sołtysiak, M., Stec, M., Zając, D. (2020). *Społeczne, ekonomiczne i środowiskowe uwarunkowania gospodarki finansowej samorządu lokalnego (przykład województwa podkarpackiego)*. Poznań: Bogucki Wydawnictwo Naukowe.
13. Jastrzębska, M. (2012). *Finanse jednostek samorządu terytorialnego*. Warszawa: Lex a Wolters Kluwer business.
14. Kańduła, S. (2010). Prawo Wagnera w gospodarce jednostek samorządu terytorialnego. *Ekonomiczne Problemy Usług, no. 61*, pp. 141-160.
15. Kata, R., Czudec, A., Zając, D., Zawora, J. (2022). *Gospodarka finansowa jednostek samorządu terytorialnego – wybrane zagadnienia*. Rzeszów: Wydawnictwo Uniwersytetu Rzeszowskiego.

16. Kopyściański, T., Rólczyński, T. (2014). Analiza wskaźników opisujących sytuację finansową powiatów w województwie dolnośląskim w latach 2006-2012. *Studia Ekonomiczne, 206*, pp. 61-73.
17. Kosek-Wojnar, M., Surówka, K. (2007). *Podstawy finansów samorządu terytorialnego*. Warszawa: PWN.
18. Kosikowski, C. (2001). *Finanse lokalne. Zarys wykładu*. Siedlce: Wyższa Szkoła Finansów i Zarządzania w Siedlcach.
19. Kotowska, E. (2016). Przesłanki racjonalnej polityki budżetowej w jednostkach samorządu terytorialnego. In: A. Gołębiowska, P.B. Zientarski (ed.), *Funkcjonowanie samorządu terytorialnego – uwarunkowania prawne i społeczne*. Warszawa: Kancelaria Senatu RP.
20. Kowalska, I., Możyłowski, P., Śmietanka, T. (eds.) (2019). *Funkcjonowanie jednostek samorządu terytorialnego w wymiarze finansowo-prawnym*. Radom: Instytut Naukowo-Wydawniczy Spatium.
21. Mrówczyńska-Kamińska, A., Kucharczyk, A., Średzińska, J. (2011). Analiza finansowa w jednostkach samorządu terytorialnego na przykładzie miasta i gminy Środa Wlkp. *Zeszyty Naukowe SGGW w Warszawie. Ekonomika i Organizacja Gospodarki Żywnościowej, 89*, pp. 175-185.
22. Natrini, N.D., Taufiq Ritonga, I. (2017). Design and Analysis of Financial Condition Local Government Java and Bali (2013-2014). *SHS Web of Conferences, 34, 03003,* https://doi.org/10.1051/shsconf/20173403003
23. Ociepa-Kicińska, E., Gorzałczyńska-Koczkodaj, M., Brzozowska, K., Pluskota, P. (2022). Ocena kondycji finansowej jednostek samorządu terytorialnego w obliczu pandemii COVID-19 na przykładzie województw samorządowych w Polsce. *Rozwój Regionalny i Polityka Regionalna, 59*, pp. 149-165.
24. Ossowska, L., Ziemińska, A. (2010). Kondycja finansowa gmin wiejskich i miejsko-wiejskich województwa pomorskiego. *Journal of Agribusiness and Rural Development, no. 4(18)*, pp. 73-85.
25. Owsiak, S. (1999). *Finanse publiczne. Teoria i praktyka*. Warszawa: PWN.
26. Poniatowicz, M. (2016). Stabilność finansowa jednostek samorządu terytorialnego w aspekcie nowej perspektywy finansowej Unii Europejskiej i zmian w systemie dochodów samorządowych. *Ekonomiczne Problemy Usług, no. 125*, pp. 7-23.
27. Rudzka-Lorentz, Cz., Sierak, J. (2006). Zarządzanie finansami w gminach. In: H. Sochacka-Krysiak (ed.), *Zarządzanie gospodarką i finansami gmin*. Warszawa: SGH, p. 183.
28. Sierak, J. (2015). Programowanie finansowania komunalnych projektów inwestycyjnych w nowej perspektywie finansowej UE 2014-2020. *Kwartalnik Kolegium Ekonomiczno-Społecznego. Studia i Prace, nr 3, t. 4: Finanse publiczne i ubezpieczenia*, pp. 173-187.

29. Sierak, J. (2017). Regionalne zróżnicowanie wielkości i dynamiki dochodów gmin i miast na prawach powiatu – analiza wskaźnikowa dla lat 2000-2014. *Finanse Komunalne, no. 1-2*, p. 77.
30. Sobczyk, A. (2010). Rozwój lokalny – wybrane problemy finansowania. *Zeszyty Naukowe SGGW w Warszawie, Ekonomika i Organizacja Gospodarki Żywnościowej, no. 81*, pp. 125-136.
31. Sołtyk, P. (2017). Uwarunkowania efektywności systemu kontroli gospodarki finansowej jednostek samorządu terytorialnego. *Studia i Prace WNEIZ US, no. 47/3*, pp. 381-393.
32. Sołtysiak, M. (2017). Budżet jednostki samorządu terytorialnego a wiedza i aktywność lokalnej społeczności. *Humanities and Social Sciences - Quarterly, Vol. XXII; Research Journal, 24(4)*, pp. 181-193.
33. Sołtysiak, M., Suraj, M. (2018). Budget of local government unit versus state of art and engagement of young generation of Poles. In: I. Majerova (ed.), *Proceedings 16thInternational Scientific Conference "Economic Policy in the European Union Member Countries"*. Silesian University, pp. 327-336.
34. Standar, A. (2017). Ocena kondycji finansowej gmin oraz jej wybranych uwarunkowań na przykładzie województwa wielkopolskiego przy wykorzystaniu metody TOPSIS. *Wieś i Rolnictwo, no. 2(175)*, pp. 69-92.
35. Stanny, M., Strzelczyk, W. (2018). *Kondycja finansowa samorządów lokalnych a rozwój społeczno-gospodarczy obszarów wiejskich. Ujęcie przestrzenne*. Warszawa: Scholar.
36. Strzelecki, Z. (ed.) (2008). *Gospodarka lokalna i regionalna*. Warszawa: PWN.
37. Szołno-Koguc, J. (2021). Samodzielność dochodowa jednostek samorządu terytorialnego – aspekty teoretyczne. *Studia BAS, no. 1(65)*, pp. 9-13. https://doi.org/0.31268/StudiaBAS.2021.02.
38. Świrska, A. (2016). Czynniki determinujące efektywne zarządzanie finansami samorządowymi (na przykładzie gmin powiatu siedleckiego). *Polityki Europejskie, Finanse i Marketing, 16(65)*, pp. 88-99.
39. Wiśniewski, M. (2011). Wyznaczniki sytuacji finansowej gminy. Ocena istotności za pomocą analizy skupień. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu. Nauki o Finansach, 9(215)*, pp. 110-119.
40. Wojciechowski, E. (2012). *Gospodarka samorządu terytorialnego*. Warszawa: Difin.
41. Wójtowicz, K. (2014a). Podział zadań publicznych między państwo a samorząd a problem zapewnienia stabilności fiskalnej jednostek samorządu terytorialnego. *Nierówności Społeczne a Wzrost Gospodarczy, no. 40(4)*, pp. 303-312.
42. Wójtowicz, K. (2014b). Udział w podatkach państwowych a problem stabilności fiskalnej jednostek samorządu terytorialnego w Polsce. *Annales Universitatis Mariae Curie-Skłodowska, vol. XLVIII.2*, pp. 135-143.

43. Wójtowicz, K. (2018). Znaczenie wybranych czynników ekonomiczno-społecznych dla kształtowania stabilności fiskalnej gmin miejskich w Polsce. *Acta Universitatis Lodziensis. Folia Oeconomica, vol. 334(2)*, pp. 213-234.
44. Zawora, J. (2015). Analiza wskaźnikowa w procesie zarządzania finansami samorządowymi. *Zarządzanie Finansami i Rachunkowość, 4*, pp. 33-45.

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RESILIENCE IN INDUSTRY 5.0 – SYSTEMATIC LITERATURE REVIEW

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Purpose: This paper attempts to explore the concept of resilience in the context of Industry 5.0. It is believed that this is the next stage of the industrial revolution of Industry 4.0. The issues addressed are new and little recognized in the literature. The aim of the paper is to examine "resilience in Industry 5.0".
Design/methodology/approach: The article uses a systematic literature review method to identify and map key words related to this topic.
Findings: The results indicate an ambiguous understanding of the concept of "resilience", but also highlight its key elements. They are common to the problem addressed in the context of Industry 5.0. These include sustainable development and human focus. The synergy between technology and people is associated with the need to adapt to changing market and crisis conditions.
Research limitations/implications: they concern the scientific works that were used to review the literature and scientific databases, the initial stage of development of the Industry 5.0 concept and the theoretical nature of the work.
Practical implications: Resilience in the context of Industry 5.0 is the least recognized pillar of this concept. The analysis indicates not only the directions of development of enterprises, but also the need to adapt employees, structures, resources and production systems in the event of a crisis.
Social implications: Knowledge of the topic of resilience does not only concern industry. The issue addressed is important in various areas of life.
Originality/value: The problem under consideration is relatively little known, mainly in the area of resilience. The mapping shows the development of work related to the problem under consideration in the context of focusing on humans and sustainable development, but also on new technologies. The need for further research has been identified, which can bring benefits to both scientists and practitioners, while promoting all pillars of Industry 5.0. The obtained results of the bibliographic analysis can constitute a knowledge base in the design of elements of production systems in enterprises, be a good example for decision-makers or the community. They can provide a background for discussions and polemics.
Keywords: resilience, Industry 5.0; literature review; sustainability, human-centric.
Category of the paper: Literature review.

1. Introduction

Rapid changes in the environment require businesses to adapt. Thanks to the integration of technologies such as artificial intelligence, automation and the Internet of Things, the industry has experienced unprecedented changes in efficiency and productivity levels. These are part of the digitalisation characteristic of Industry 4.0.

The transition to Industry 5.0, which emphasises human collaboration, sustainability and resilience, is expected to bring new opportunities and challenges for both employers and employees. The integration of technology with human skills is expected to provide a remedy in the form of 'industry resilience' to economic changes and crises. The ability to adapt and respond to changing conditions not only for industrial companies but also for other organisations is the future of building their 'resilience' to change.

The 'resilience' trend shaping Industry 5.0 is precisely linked to the ability to adapt and respond quickly to changing conditions.

In the literature, despite numerous items on Industry 5.0, 'resilience in Industry 5.0' is not explained in depth. This constitutes a research gap which is also a research problem addressed in the question: what is "resilience in Industry 5.0"?

The relevance of this study and its contribution to the scientific literature is determined by the fact that in human communication every word has a meaning. Understanding the nature of words, especially in science, is important in terms of communicating information accurately and building shared understanding. The expressions 'resilience' and 'Industry 5.0' are used by the European Commission to indicate the direction of the economies and societies of the associated countries. Not only governments, but also all members of the EU member states should be aware of the concept of 'resilience in Industry 5.0'. This formulation will be analysed in this paper.

The issue addressed by combining the word 'resilience' with Industry 5.0 stems not only from technological developments, but also from changes taking place in the political, economic and environmental arenas. The pace of change through digitisation, the use of technological solutions in various spheres of life, is so fast that we are often unable to keep up with the information that is also coming at us exponentially.

The volatility of the environment under the influence of crises should also be mentioned. The pandemic revealed weaknesses in global supply chains, demonstrating the importance of adapting quickly to disruptions (DeWit et al., 2020; Villar et al., 2023; Huang et al., 2022; Mourtzis et al., 2022b).

The production process can also be disrupted by weather events (Foresti et al., 2019; Bakon et al., 2022). Increasingly frequent floods or droughts point to the need to build production systems that can quickly adapt to the prevailing condition. In the Industry 5.0 concept, this involves the implementation of new technologies. Related to this is the integration and adaptation that protects the environment as a priority in sustainable development. Human beings and their place in the transformation processes taking place during the implementation

of technological solutions are also important. Therefore, the aim of this paper is to explore 'resilience in Industry 5.0'.

In addressing the stated objective, the following research questions were formulated:

1. How is 'resilience in Industry 5.0' defined in the literature?
2. In which areas can 'resilience in Industry 5.0' be considered?
3. What were the main research trends in the field of Industry 5.0 and resilience in 2021-2024?

The present work is structured as follows.

The Introduction section provides context and introduces the topic, also indicating the motivation and research gap of this paper. The second section presents definitions of resilience in Industry 5.0. The next covers the methodology of the systematic literature review. The fourth presents the findings gathered from the literature review based on qualitative studies of theses. The fifth covers the network analysis of publications using VOSviewer. The next section includes a discussion. The final section concludes this paper with conclusions including practical implications and suggestions for future research.

2. Definition of „resilient in Industry 5.0”

In 2021 The European Commission formally called for a fifth industrial revolution (Industry 5.0) in the document 'Industry 5.0: Towards a sustainable, people-centred and resilient European industry' issued on 4 January 2021 (European, 2021).

It states "building resilience within our existing economy and transforming to a new set of economic ecosystems that are more resilient to future shocks and stresses should be Europe's mission henceforth. Ensuring that European industrial development is oriented towards resilience whilst enabling and accelerating the transition to the age of sustainable wellbeing for all is an essential step for the future of the EU industrial strategy (European, 2021, p. 3).

It was noted that 'transformation means, first of all, mainstreaming resilience, sustainability, regenerative and circular economic principles in all its policies, and in the implementation of those policies, from Horizon Europe to the national plans for resilience and recovery' (European, 2021, p. 4).

The transformation from Industry 4.0 to Industry 5.0 (Fraga-Lamas et al., 2021; Golovianko et al., 2022; Grabowska et al., 2022; Mourtzis et al., 2022a) is the process of how we view and use technology in industry. Industry 4.0, focuses on the automation, digitisation and integration of manufacturing systems through technologies such as the Internet of Things (IoT), artificial intelligence (AI) and data analytics. A description of Industry 4.0 can be found in numerous works (Andres et al., 2024; Borchardt et al., 2022; Ghobakhloo et al., 2024; Grosse et al., 2023; Hansen et al., 2024).

The concept of Industry 5.0 allows companies to take a broader perspective and provide solutions to emerging societal challenges (Document, 2024). "Industry 5.0 updates and extends the concepts of Industry 4.0, focusing on what has been called the 'three Ps': people, planet and prosperity" (Document, 2024).

The concept of 'resilience' was known in the literature before it was defined in European Commission documents. The origin of the word is briefly presented below.

The word "resilience" has its origin in the Latin word "resi-lire", which means springing back. The concept of resilience has become a ubiquitous concept rooted in different worldviews and scientific traditions such as psychology, ecology, and engineering. The concept of resilience evolved from psychology in the 1940s. Resilience entered the field of ecology when systems thinking became popular. Crawford Stanley Holling (1973) defined a concept of ecological resilience in order to "understand the capacity of ecosystems with alternative attractors to persist in the original state subject to perturbations" (Resilience, 2021).

In social terms, it is defined by Adger (2000) as social resilience, the ability of groups or communities to cope with external stresses and disruptions caused by social, political and environmental change.

From an economic perspective, it is the innate ability and adaptive responses that allow companies and regions to avoid maximum potential losses (Rosa, Liao, 2005).

From a management point of view, it is the ability of an organisation to cope with stresses and improve performance despite adversity (Vogus, Sutcliffe, 2007).

In engineering terms, it is the ability of a system to survive a major failure with acceptable degradation parameters and to recover within an acceptable time, taking into account cost and risk (Haimes, 2009; Kaz, 2019).

This 'capacity' to withstand and quickly recover from disruption is referred to in the European Commission document. to the economic crisis caused by a pandemic. With the Instrument for Recovery and Resilience, the European Commission wants to support EU countries in reform efforts that ensure sustainable recovery (Breque, De Nul, Petridis, 2021).

Further challenges are related to climate change, financial crises, energy crises, an ageing population, armed conflicts, trade wars, protectionism, etc.). Both these and other challenges point to the need to adapt to them. Indusrty 5.0 points to designing businesses in such a way that the industry is robust, adaptable and able to maintain operational integrity under adverse conditions. Confirmation of these indications can be found in the work of Thomassen, Henriksen, (2023), Wachter et al. (2024), Atif, Qureshi, (2024), Wolniak (2023) among others.

Breque, Nul, Petridis (2021) point out that resilience refers to the need to develop a higher degree of robustness in industrial production, better arming it against disruptions and making sure it can provide and support critical infrastructure in times of crisis.

The industry of the future must be equipped to adapt quickly to changing circumstances. Only then can it cope with unforeseen situations (disruptions), which can occur at many levels, including the shop floor, the supply network and the industrial system.

Resilience is defined: as a response, a reaction to a situation that is different (e.g. illness, lack of energy, etc.) from the actual situation (expected, normal, functional).

Resilience is related to the capacity and ability of a business to recover from a disruption. Resilience, of a business can be measured by its ability to cope with risk and reduce vulnerability.

In the context of Industry 5.0, resilience is an important aspect that enables organisations to survive disruptions and continue operations seamlessly. As Industry 5.0 emphasises the integration of advanced technologies such as artificial intelligence, big data analytics and the Internet of Things (IoT), manufacturing systems are becoming more complex and vulnerable to failure. Therefore, building resilient production systems is crucial to mitigate the impact of disruptions and ensure business continuity (Kaasinen et al., 2022; Lee et al., 2022, Akungj et al., 2022).

3. Methodology

Documentation of the systematic review was carried out according to the guidelines given in the PRISMA (2020) statement (Fig. 1).

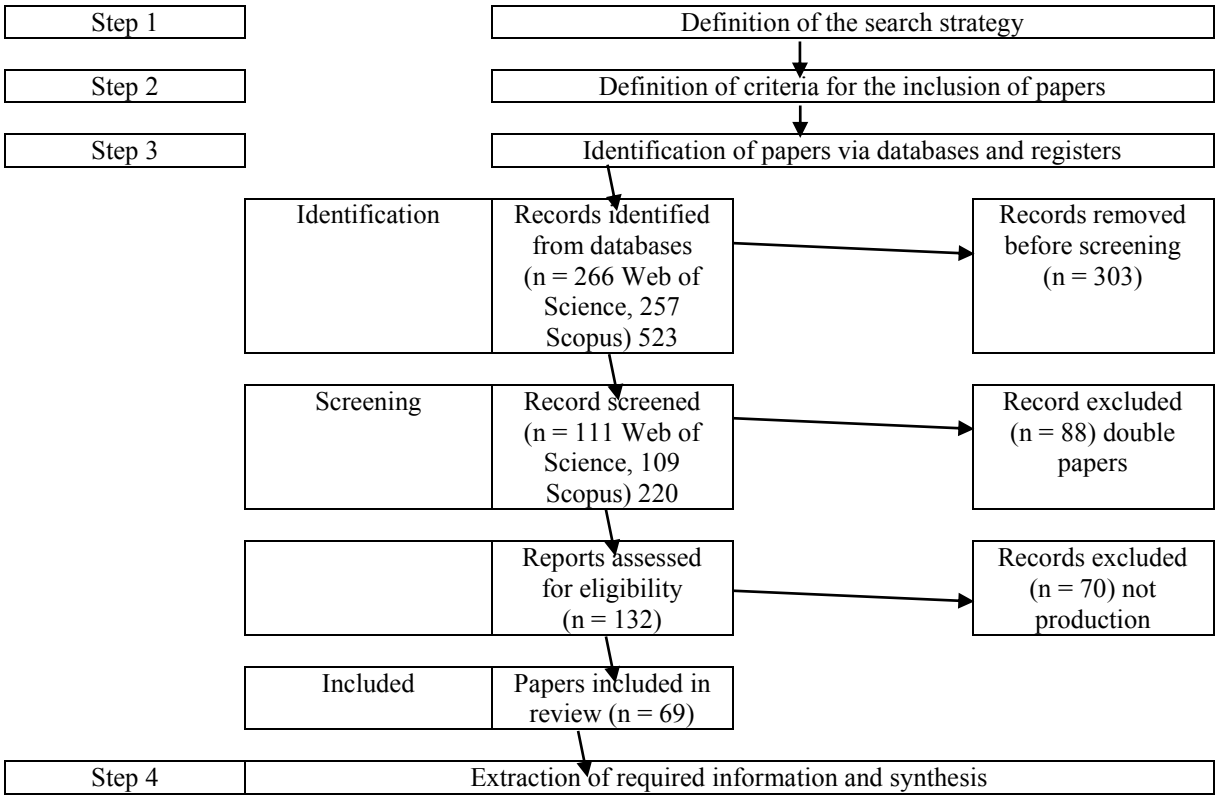

Figure 1. Steps of systematic literature review.

Source: based on The PRISMA 2020.

Planning the literature review involved selecting two databases: Web of Science and Scopus. Pre-determined keywords were used to search the database, which are related to the main purpose of the study. The keywords were chosen to be comprehensive and not to condition or limit the study. The predetermined search equation was ('resilience') AND ('Industry 5.0') OR ('resilient') OR ('Resilience') and was used in an advanced Web of Science search. The syntax was then adapted to the Scopus database: (TITLE-ABS-KEY). The search was conducted in English.

Selected article search locations were in the title and abstract. 523 papers were identified. The search period for the articles was limited to the years 2021-2024. 2021 was chosen as the beginning of the period because it was the year when Industry 5.0 began to be discussed. A selection process was then carried out for eligibility using the following inclusion/exclusion criteria: only full-text studies published in English, including research articles, review articles and conference proceedings that present and explore at least one of the two main themes of the study.

The fact that work occurring in databases without full access is not included should be considered as one of the research limitations.

Finally, a consolidated list of the remaining articles (220) was downloaded and saved to a file on the researcher's laptop for convenient access later (database status 26.01.2025). The documents retrieved from the Scopus and Web of Sciencie databases were collated in Excel baize and duplicates were removed manually.

Articles relating to resilience in agriculture, energy or areas of activity other than industry, or that did not reflect the main objective of the study, were also excluded. The hypothesis was accepted that the authors more often took up the issue of resistance analyzed in terms of technological solutions in their works. Finally, 69 papers were accepted for analysis and read against the research assumptions.

Next: graphical analyses were performed using VOSviewer No. 1.6.20.0, which is a software tool widely used to construct bibliometric studies and network analysis (Bajaj et al., 2022; Hanaa, Abdul, 2023). The category of analysis by keyword, visualisation by year, was used to evaluate and characterise the papers. The above categories helped the author to gain a deeper understanding of key variables in a structured way to uncover gaps in qualitative research. The maps work by categorising the field into distinct research clusters that illustrate keywords as points on a map. The spatial arrangement of these points - how close or far away they are - reflects the frequency with which related concepts are discussed in the literature. Points that are clustered close together suggest a large amount of published literature on these topics, while points that are more dispersed indicate areas with less scientific focus. Conceptual structure maps are particularly useful for detecting citations associated with specific keywords, which can help identify emerging research trends (Cobo et al., 2011).

4. Contextualised study of resilience

When starting the analysis of the papers, it was assumed that they would be reviewed in terms of the authors' take on the phrase 'resilience in Indusrty 5.0'. The following definition of resilience was adopted for comparison and analysis: the ability and capacity of an enterprise to return to its state after a disruption. From reading the papers, there were several areas with which the analysed phrase was linked.

In the 69 papers reviewed in detail (appendix 1), the authors emphasise that resilience is one of the three key pillars of Industry 5.0, alongside sustainability and human-centric.

In most of the papers analysed, 'resilience' is defined as the ability of a system to adapt and continue to operate effectively in the face of disruption. It can therefore be concluded that, in the most general terms, the authors adopt the definition of resilience proposed by the European Commission (see Aldea et al., 2021).

A similar definition is presented in the context of manufacturing systems, within which two areas of resilience use have been identified: supply chains and risk. Resilience refers to the design of resilient systems that incorporate strategic redundancy and flexibility so that they can adapt to various unforeseen factors, such as supply chain disruptions, changes in market demand or natural disasters (Agote-Garrido et al., 2023).

Alves, Lima, Gaspar (2023), Mourtzis et al. (2022 a) define 'resilience' as a key element in the context of Industry 5.0, which involves creating more resilient and sustainable production systems. The definitions cited are general in nature. In most of the papers, the authors combine the three components of Industry 5.0 capturing sustainability, human-centric and resilience together.

The concept of 'resilience' occupies a central place in the context of industrial transformation, (Johansen, Akay, 2022; Hunkova, Haviernikova, 2024). In this area, authors define 'resilience' in a variety of ways, including technological, organisational and social aspects. This allowed us to obtain answers to research questions 1 and 2.

This observation when reading the texts led to the formulation of an additional research question: do the phrases 'sustainability', 'human-centric' and 'resilience' have equivalent meanings, or does one of them override the others?

The term 'resilience' is often treated in close association with 'sustainability' and 'human-centricity' so it is difficult to clearly demarcate. This is particularly evident in works referring to the pandemic as a crisis (Romero, Stahre, 2021; Ahmed et al., 2023). As a result of the COVID19 pandemic, companies had to transform their business models. But not only that.

The articles show that the meaning of the words and their overarching nature depends on the context of the analysis. In works describing the transition from Industry 4.0 to Industry 5.0, the authors emphasise that the triad of relationships: human-centric, resilient and sustainability forms the basis of the Industry 5.0 concept (Grabowska, Saniuk, Gajdzik, 2022), treated equally.

Resilience is a key element of Industry 5.0, while at the same time it is the future of action not only for industry.

A different way of presenting the phrase 'resilience in Industry 5.0' refers to the presentation of 'resilience' as a 'sub-element' resulting in 'improvements' that translate into the environment or humans.

However, it similarly covers areas such as sustainability and human-centric. This points to a complex interaction between technological efficiency and social and environmental needs. It is resilience that is the connecting element, welding together the activities that translate into the other two pillars of Industry 5.0. It can be said that it 'fills', 'enriches' production activities. Mostly involuntarily because if something functions without errors little attention is paid to resilience. Perception changes in the event of disruptions, crises. Then the aim is to regain the agility of the production system and 'resilience' is in focus.

Central to this is respecting core values in the design of technologies to ensure that technologies serve people and improve social and environmental well-being (Agote-Garrido et al., 2023; Romero, Stahre, 2021). This approach points to a broader definitional context but still connects with the main pillars of the concept.

In the context of **sustainability**, the authors (Kour et al., 2024) indicate that resilience is supposed to lead to sustainable performance. After disruptions, production systems are supposed to maintain profitability and not have a negative impact on the environment.

At the same time, actions are identified to ensure 'resilience'. These include, for example, technology integration (Agote-Garrido et al., 2023), socio-technical design of production systems (Kour et al., 2024), cybersecurity challenges (Kour et al., 2024).

It should be noted that implementing sustainability in a company does not depend on 'resilience' alone. It requires extensive collaboration between multiple stakeholders'. The authors' work focuses on the mutual benefits of the synergies between sustainability and ensuring industry resilience (Chavez, 2022; Abuhasel, 2023; Ismail et al., 2024).

Human-centric as a pillar of Industry 5.0 aims to put people back at the centre by leveraging advances in digital technologies. Integrating resilience and human-centricity in Industry 5.0 involves creating systems that are not only efficient and sustainable, but also adapt to human needs and are able to withstand disruption.

The combination of 'resilience' and 'human-centric' is a key element of the new industrial paradigm. Industry 5.0 emphasises the integration of innovative technologies with the active participation of people, which means that production not only needs to be digitised, but also resilient, sustainable and human-centred. This strengthens not only the resilience of production systems to disruption, but also influences sustainability and social well-being (Alves et al., 2023). Again, despite the foregrounding of the 'human-cenrtica' this time, resilience has a servant function.

A resilient approach within Internet of Things (IoT) - based manufacturing strategies is crucial to maintain the continuity of manufacturing operations and the supply chain, especially in the face of global crises. The use of human-robot collaboration in assembly lines aims to increase productivity, which at the same time leads to better employee wellbeing (Nourmohammadi et al., 2022). The aforementioned authors also point to several areas specific to building resilience. Industry 5.0 proposes that employment structures and digital strategies should be tailored to people, highlighting the importance of human involvement in production processes (Leirmo, 2024; Leng et al., 2022). Data security is also important (Andres et al., 2024).

Resilience is also considered from the side of competence, skills, human adaptation to use, use of elements of the production system (Alves et al., 2023).

A trend towards **collaboration** can also be seen in the work. Resilience in Industry 5.0 not only strives for efficiency and productivity in production systems, but also strengthens the role of workers, all the while respecting global production constraints (Abdous et al., 2023). In this context, resilience is defined as the ability to develop innovative technologies and workplaces in a human-centred way. This is to enable the creation of an effective and safe working environment and also a robust collaboration between humans and machines (Barata, Kayser, 2024). Resilience is also described as a key element that strengthens these production systems so that they can respond effectively to unexpected problems and adapt to changing conditions over the long term (Afzal, Li, Hernández-Lara, 2024).

Contemporary approaches to resilience integrate human and technological aspects to lead to better management of operational systems and improved quality of life for workers. The use of assistive technology systems such as collaborative robots (cobots) and exoskeletons is mentioned, which aim to optimise production processes, ergonomics, taking into account the diversity of the workforce (Grosse, 2023).

In the context of human-robot collaboration in industry, ethical approaches are also being considered to create a well-structured framework to govern future practices (Callari et al., 2024). Ethical approaches must not only cover the operational aspects of collaboration in the factory environment, but also be guided by more broad principles of organisational and social governance, resulting in a more responsible integration of advanced robotics into the professional environment (Camarinha-Matos et al., 2024; Callari et al., 2024; Gródek-Szostak et al., 2023; Kehrbusch et al., 2023).

Related to collaboration is **technology integration** referring to the ability of technological systems to maintain functionality and continue production.

The articles analyse different resilience strategies that take into account the integration of modern technologies such as artificial intelligence, digital twins and blockchain (Leng et al., 2022). The authors point out that blockchain technology can help eliminate the risk of a single failure in the context of resilient manufacturing systems by decentralising IIoT (Industrial Internet of Things) data management.

Nourmohammadi et al. (2022) present digital twins that can support resilience in the manufacturing industry through real-time data collection and analysis. This enables faster decision-making in the face of disruption. The use of adaptive technologies, improves the quality of final products (Lerimo, 2024). With intelligent sensors and devices that collect realtime data, organisations can identify problems, minimise downtime and optimise resource utilisation (Lerimo, 2024).

An important solution highlighted by Domenteanu, Cibu, Delcea (2024) is predictive maintenance systems that monitor the condition of machines and predict failures before they occur, leading to less downtime and increased operational efficiency. This is an example of building resilience within a production system.

Adaptability is linked to the new technological solutions being introduced. In the adaptation perspective, resilience is presented as a key aspect needed to adapt and survive in a changing industrial environment (Camarinha-Matos, Rocha, Graça, 2024).

In detail, the term 'reilience' is replaced by 'transformative resilience', which describes systems that not only defend themselves against disruptions, but also reorganise, reconfigure, restructure and even reinvent themselves in response to these disruptions (Camarinha-Matos, Rocha, Graça, 2024).

In terms of adaptation, resilience is seen as the ability to anticipate and respond quickly to operational disruptions that may threaten the value of the business. For example, in relation to information systems, resilience is a function of an organisation's overall situational awareness of information systems gap management and the adaptability, risk intelligence, flexibility and agility of information systems in a complex, dynamic and connected environment (Aldea et al., 2021).

The integration of advanced technologies and the increasing complexity of modern production systems introduces new challenges, such as the risk of cascading failures. Therefore, identifying effective resilience strategies becomes crucial to maintain system integrity, minimise downtime and improve product and process quality (Watcher et al., 2024). Many works do not have a consistent line of analysis of 'resilience in Industry 5.0'. Multifaceted, multi-tracking is a feature of building resilience in different areas of the production system.

The most common work found in the literature describes resilience in the context of **supply chains** as the ability to respond and recover effectively from unexpected disruptions. It consists of two key elements: 'vulnerabilities' and 'capabilities'. Vulnerabilities refer to factors that increase an organisation's vulnerability to unpredictable disruptions, while capabilities refer to characteristics that allow organisations to anticipate, mitigate and recover from such disruptions (Dacre et al., 2024). Maintaining data integrity and enabling decentralised decision-making whether in the previously mentioned supply chains or cyber security are other areas where 'building resilience' is indicated (Fraga-Lamas et al., 2024; Radid et al., 2024). Supply chains are an area identified in European Commission documents, but resilience is important for

companies to meet increasing demands and changing market conditions (Ahmed et al., 2023; Isamil et al., 2024).

Risk in the definition of 'resilience' is important for business continuity in the face of disruption, as pointed out by Atif (2023). Risks are already associated with the industrial transformation itself, especially in the context of the transition from Industry 4.0 to Industry 5.0. Identifying risks is a key element in assessing manufacturing innovation. A study by Ghobakhloo et al. (2024) presents a multi-criteria decision-making approach that uses fuzzy set theory, integrating different criteria to assess innovation.

Callari, Vecellio Segate, Hubbard, Daly, Lohse (2024) point to the challenges of skills gaps, that require collaboration between employers, employees and educational institutions to ensure the development of appropriate skills, which can also affect risk in production processes (Callari et al., 2024; Gartner et al., 2023).

In each of the contexts analysed, resilience appears in combination whether with the other pillars of Industry 5.0 or in the context of the areas to which adaptation applies. Such thematic diversity points to the need to harmonise and build on the concept of resilience in industry.

This is supported, for example, by the focus of 'resilience' on short-term and long-term functionality, where short-term refers to the ability to return to normal operating conditions after short-term consequences and long-term is defined as the ability to continuously adapt in response to long-term disruptions (Saniuk, Grabowska, Straka, 2022; Aldea et al., 2021).

"Resilience" in the context of Industry 5.0 is a complex concept that requires the integration of many elements. Examples include work on failure management, which points to the need to identify effective resilience strategies to maintain system integrity and minimise production downtime (Wachter et al., 2024). One can also find work pointing to building stakeholder value (Dacre, 2024; Castagnoli, 2024).

Rejeb points out that all systems (social, economic, economic, environmental) must in resileince avoid (anticipation), withstand (absorption), adapt (reconfiguration) and recover (restoration) in response to anticipated and unanticipated disruptions (Rejeb et al., 2024).

The work highlights the need for effective measurement methods to enable companies to determine their current level of resilience maturity and identify areas for improvement.

5. Network analysis of publication

After qualitative analysis of the papers using the VOSviwer programme, a keyword map was generated based on bibliometric data from the Web of Science and Scopus databases. The analysis included scientific papers published between 2021 and 2024 on Industry 5.0 and resilience topics. The aim of the analysis was to identify the main research themes and their interrelationships (Table 1).

Table 1.
Clustering keywords

Keyword	Occurrences	Total link strength
Industry 5.0	54	105
Industry 4.0	22	59
Sustainability	17	56
Resilience	15	49
Human-centricity	6	25
Human-centric	6	17
Society 5.0	5	17
Digital transformation	4	13
Human factors	4	12
Artificial intelligence	5	10
Digital twin	4	10
Digitalization	3	10
Resilient	4	10
Human-robot collaboration	4	9
Operator 5.0	3	8
Sustainable development	3	8
Digitalization	3	7
Ergonomics	3	7
Manufacturing	3	7
Sustainable manufacturing	3	7
Human-centric manufacturing	4	6
Resilient production	3	5
Smart manufacturing	3	3

Source: Authors' elaboration.

The analysis included 516 author keywords with 23 linking words. The map consists of 5 nodes (keywords) and 230 lines (links between keywords). The colours of the nodes represented the different 5 thematic clusters, and the size of the nodes reflects the frequency of the keyword in the articles analysed (fig. 2).

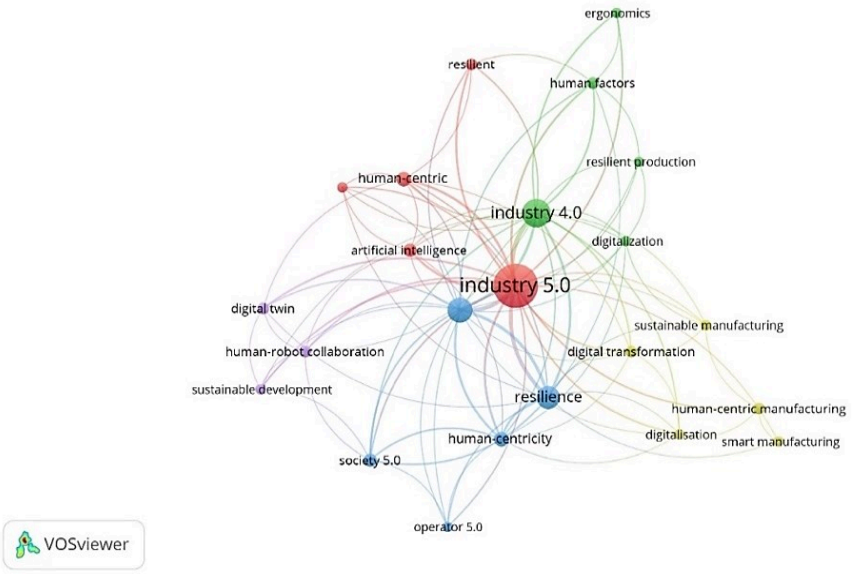

Figure 2. Keyword map**.**

The map shows the homogeneity of the data analysed. All keywords were clustered around Industry 5.0 forming the largest node of the red cluster. The words are clustered into one large node, which demonstrates the homogeneity and correctness of the selection of papers for analysis.

Red cluster: is a cluster centred around the Industry 5.0 theme, with the largest node indicating the popularity of the issue addressed by the authors. At the same time, it is a central theme that links all keywords with strong links (links: 22, total link strength: 105, occurrences: 54). Total link strength is a measure that indicates the total strength of all links of a node to other nodes in the network. It is the sum of the link strength values between a given node and all other nodes to which it is connected (VOSviewer map and network files - VOSviewer Online Docs). A high value of total link strength 105 suggests that a node is strongly connected to many other nodes, which also indicates its central role in the network. This is confirmed by the presence of links in 54 studies. Despite the central link in red, link sthrength 4 indicates an association with the keyword "resilient". The cluster also includes the words artificial intelligence, human-centric, manufacturing.

This cluster can be characterised as grouping publications on the directional principles of the Industry 5.0 concept, which connects through lines and links to the other clusters.

Green cluster: brings together themes relating to Indusrty 4.0, digitisation, ergonomics, human factors, resilient production. Total link strength in the green cluster was 59, occurrences 22, which also indicates a strong link with other nodes.

Blue cluster: contains two dominant nodes: "sustainability" and "resilience". The theme of 'sustainability' is very popular among authors. This is confirmed by the total link strength of the value 56. Similar link strengths and connects the theme of 'sustainability' with 'human-centricity', operator 5.0, resilience, sociality 5.0.

Yellow cluster: concerned digitisation. It was formed by the nodes 'digital transformation, digitisation, human-centric manufacturing, smart manufacturing, sustainable manufacturing'. It has a stronger link to the Industry 5.0 call and its location - more distant - indicates a focus on themes that will dominate the future.

Purple cluster: centred around human-robot collaboration. It is formed by digital twin, sustainable development. Connected is total link sthrehgh 9, occurrences 4.

The words 'resilience' included in the blue cluster, 'resilient' in the red cluster and 'resilient production' in the green cluster do not account for the difference in meaning in the key word. Assigning them to different clusters despite their similarity in meaning is due to the strength of the combination with other words and also the time (year) of publication of the work. Also related to this is the framing of the issue of 'resilience' in the context of 'Industry 4.0', where the focus was on other elements of the concept. In the 'Industry 5.0' concept, the keyword is one of the elements describing the concept. In contrast, 'resilience' in the blue cluster is linked by the themes of 'sustainability' and 'human centricity', indicating the need for specific adaptations to the context.

The map vividly reflects the keyword links in the articles analysed in four section of this thesis. The map clearly shows the linkages and attribution to word context. The quantitative analysis confirms the qualitative analysis, from which the linking of the issue of 'resilience' and 'Industry 5.0' to other issues (on the map by keywords) was evident.

Analysis of the keyword map identified the main research areas within 'Industry 5.0' and 'resilience' and their interrelationships. The key themes were advanced technologies 'Industry 5.0, Industry 4.0, sustainability, artifical intelligence, human-centric.

The Overlay Visualisation map indicates that Indusrty 5.0, resilience, and digital transformation in which digital twin and human-centric were the most popular issues in the latest 2024 analysis period (fig. 3).

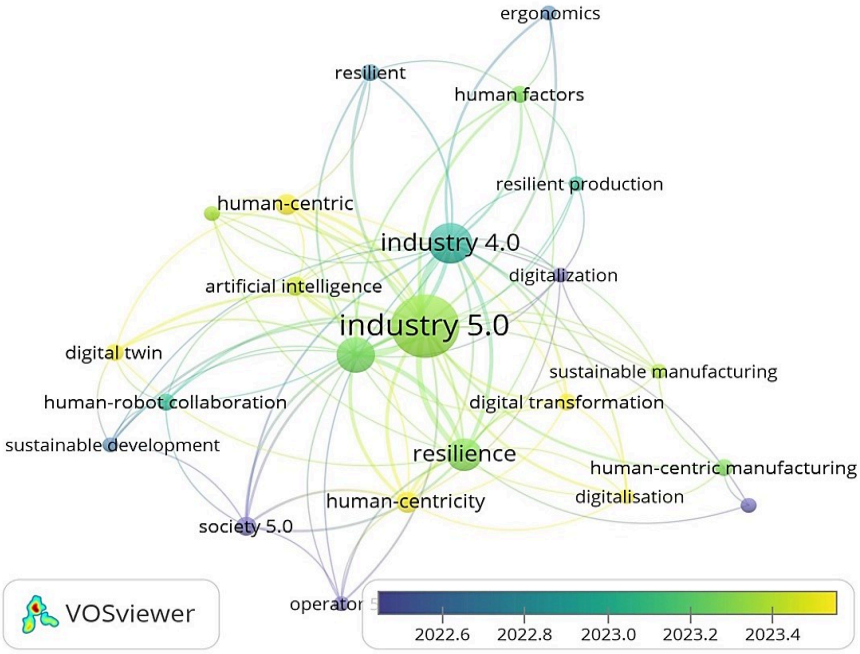

Figure 3. Overlay Visualization.

The keyword map generated in VOSviewer provides valuable information on the structure and dynamics of research in the field of 'resilience and Industry 5.0'. The analysis of the clusters and the links between them allows for a better understanding of the main research themes and their interrelationships. It also made it possible to answer the research question posed: what were the main research trends in the field of Industry 5.0 and resilience between 2021 and 2024?

The dominance of 'Industry 5.0' issues stems from the shift from 'Industry 4.0' analyses to a new concept that places greater emphasis on integrating advanced technologies with human skills and sustainability. The high value of total link strength between these keywords indicates intensive research into how Industry 5.0 technologies can support the resilience of manufacturing systems.

The keyword 'resilience' is linked primarily to the Industry 5.0 theme but also to 'sustainability' and 'human-centricity'. This confirms the exploration of topic that are embedded in the ideas of Industry 5.0.

Sustainability is a key element of Industry 5.0 and research often focuses on how technologies can support green and sustainable manufacturing practices.

The issue of 'sociality 5.0' and 'human-centricity' as areas of adaptation to change is and will continue to be important in the future. "Human-centricity", on the other hand, emphasises the role of humans in production and technological processes, which is key to Industry 5.0. Research often looks at what technologies can be adapted to the needs of humans and how they can support their development.

From the map you can see developments in the area of 'digitalisation' and 'artificial intelligence', The digitalisation of manufacturing processes and the use of artificial intelligence are key future elements of Industry 5.0, with research focusing on how these technologies can support the resilience of manufacturing systems and sustainability. These links suggest that future research will continue to explore these areas. This helped to confirm the authors' hypothesis of a more frequent interest in resilience in technology solutions.

The links between 'resilience' and 'Industry 5.0' are key to understanding how modern technologies can support 'resilience' in industry. Research in these areas is interdisciplinary, linking technology with ecology, risk management and human-centricity. Future research is likely to continue to explore these themes, looking for new ways to integrate advanced technologies into the worker and production.

6. Discussion

Industry 5.0 emphasises human-centricity, sustainability and resilience, building on the digital achievements of Industry 4.0.

Resilience in this context refers to the ability of production systems to withstand and rapidly recover from disruptions such as pandemics, energy crises and supply chain problems.

The multifaceted approach locates 'resilience in Industry 5.0' as one of the pillars, which intersect with descriptions indicating adaptations targeting one selected pillar, e.g. human-cenrtic. This allowed the question of defining 'resilience' to be answered. Definitions of resilience vary depending on the research perspective. Resilience in Industry 5.0 is a focus on creating a more sustainable, human-centred and adaptable industrial environment. The analysis shows that resilience is defined in terms of specific areas such as sustainability, human-centric, technology integration, adaptation and human-machine collaboration.

According to Cortés-Leal, Cárdenas, Del-Valle-Soto (2022), areas where resilience is relevant include, but are not limited to: production processes, risk management and people-resource connections. Increasingly, however, resilience is related to various aspects of an organisation, including its culture, leadership effectiveness and innovation skills.

In the literature, we also increasingly find work on 'resilience' framed, e.g. in the context of sustainibility relating not only to industry but to agriculture, urban planning (Kumareswaran, Jayasinghe, 2023).

Attention is also given to policy and planning for sustainable development goals (Roostaie et al., 2021; Roostaie et al., 2019; Keenan et al., 2021; Erp et al., 2024; Marlow et al., 2023).

In the context of the increasing importance of technology in responding to disruption, the literature highlights the importance of using advanced technological solutions as a key element in building resilience in the new industry.

Key research trends in Industry 5.0 and resilience in 2021-2024 include an interest in adaptive resilience, the integration of modern technologies with the pursuit of sustainability and human-machine collaboration. The literature highlights the need for an ethical framework for collaborating with robots and the challenges of skills gaps, which is essential for effective response to disruption. All research trends link to the concept of Industry 5.0.

"Resilience in Industry 5.0" is presented in a holistic approach. The multiple, diverse, complex, interpretations cause difficulties in analysing and evaluating the works.

The key role of resilience in the context of Industry 5.0 focuses on the industry's ability to adapt to changing conditions. Transformation, however, is more sustainable and human-centred (Wan, Leirmo, 2023; Kulkarni, Patil, 2024; Lu, 2022).

Central to the vision of a resilient industry is the inclusion of human input in manufacturing processes. The integration of human-robot collaboration patterns aims not only to improve efficiency, but also to free workers from monotonous, routine activities, which can ultimately increase the value that humans bring to industry (Davim, 2025).

As a result, the discussion on resilience in Industry 5.0 not only focuses on the technological aspects, but also on the integration of people. The whole thing, according to the European Commission, is to contribute to building sustainability.

7. Conclusion

The European Commission's Industrial Strategy for Europe presents a comprehensive vision for the future of European industry, emphasising the importance of digitalisation, innovation and sustainability. Industry 5.0 differs from Industry 4.0, which focused on automation and digitisation of processes, on the integration of human skills with advanced technologies. Industry 5.0 seeks to create a symbiotic relationship between humans and machines.

Industry 5.0 represents a transformational vision for the future of European industry. By seizing the opportunities offered by Industry 5.0, Europe can become a role model and shape a better future for future generations.

The concept of 'resilience in Industry 5.0' exhibits a multifaceted nature, encompassing technological as well as human and environmental dimensions. Faced with the increasing challenges of dynamic market changes and crises, integrating advanced technologies with human skills becomes crucial. Industry 5.0 focuses on sustainability, human-centric, functional and safety, which emphasises the need for adaptation and continuous learning in the working environment.

A systematic literature review presents a comprehensive approach to exploring the concept of resilience, especially in the context of a new industrial philosophy such as Industry 5.0. The definition of resilience is ambiguous. This variation makes it difficult to understand the key elements of building resilience, in this rapidly evolving industrial context.

The need to integrate technology with human skills and to adapt to rapidly changing market, environmental conditions was identified. This is important in the context of future research directions on digitalisation.

Ultimately, further exploration of resilience issues is needed. The interaction between technology and humans may prove to be the foundation of a future, more resilient and sustainable economy. This also requires promoting sustainable practices, innovative approaches and building partnerships that will benefit not only businesses but society as a whole in the long term. These transformations, while complex, represent an opportunity to create a better future for an industry that is responsible for shaping people's everyday lives.

Research limitations are related to a gap in research. There is a lack of standardised resilience solutions and a comprehensive framework to guide the integration of resilience in Industry 5.0. This is because research in the field of 'resilience' and 'Industry 5.0' is still at an early stage. It is difficult to identify directional syntheses from the studies analysed. The literature is fragmented across disciplines and methodologically rigorous quantitative, qualitative research is lacking.

The ambiguity of the definition and scope of Industry 5.0, as well as the limited understanding of its technological components, results in a lack of uniform consensus on the issue of 'resilience'. In the case of the present work, it is important to point out the methodological limitation associated with the use of open access articles. There are quite a few papers in databases where access is limited.

It should be noted that the issues addressed focus on theoretical approaches, while the few empirical works are limited to the analysis of case studies in the technological field.

The concept of Industry 5.0 encourages authors to undertake considerations within three pillars: human-centric, sustainability and resilience, which can introduce errors in the focus of research and its categorisation into the appropriate thematic group. Potential errors may arise from the emphasis on anthropocentricity, sustainability and resilience pillar.

Practical implications: The limitations identified may contribute to further work. The discussion may focus on the practical application of the research results.

Companies operating in the EU under the Indusrty 5.0 concept face new challenges and opportunities. However, the implementation of Industry 5.0 technology requires investment in employee training, digital infrastructure. Subsequently, there is a need to ensure compliance with regulations in the environmental area.

Practical implications relate to promoting the theme of resilience when implementing technological solutions, building human-machine interaction. This is in line with the framework of the European Industrial Strategy.

Suggestions for the future: the authors often suggest directions for future research that can develop or complement their findings. Exploring the issue of resilience, is essential to fully exploit the potential of Industry 5.0. Production systems need to be flexible, but also resilient to the various challenges posed by modern times.

Resilience has to take into account the economic sphere in addition to the social and sustainability elements. Related to this is the need for cost-effectiveness analyses of investments in innovative solutions, monitoring costs so as to develop the most effective production resilience strategies. The need to develop uniform tools to measure resilience so that the effects of adaptations can be compared.

In summary, the conclusions from the literature review suggest that for companies to operate effectively in the Industry 5.0 era, they need to focus on building flexible, adaptive structures that not only respond to change, but also re-engineer and improve their processes. Further research in this area will be key to understanding and developing the full concept of resilience in Industry 5.0 and its application in practice.

References

1. Abdous, M., Delorme, X., Battini, D., Berger-Douce, S. (2023). Multi-objective collaborative assembly line design problem with the optimisation of ergonomics and economics. *International Journal of Production Research*, *61/22,* 7830-7845. https://doi.org/10.1080/00207543.2022.2153185.
2. Abuhasel, K. (2023). A Zero-Trust Network-Based Access Control Scheme for Sustainable and Resilient Industry 5.0. *IEEE Access*, *11*, 116398-116409. https://doi.org/10.1109/ACCESS.2023.3325879.
3. Adger, W. (2000). Social and ecological resilience: are they related? *Progress in human geography*, *24(3),* 347-364.
4. Afzal, B., Li, X., Hernndez-Lara, A. (2024). The innovation journey and crossroads of sustainability, resilience and human-centeredness: a systematic literature review. *Transforming Government: People, Process and Policy*. *18, 3,* 368-383. https://doi.org/10.1108/TG-10-2023-0151.

5. Agote-Garrido, A., Martin-Gomez, A., Lama-Ruiz, J. (2023). Manufacturing System Design in Industry 5.0: Incorporating Sociotechnical Systems and Social Metabolism for Human-Centered. *Sustainable, and Resilient Production Systems*, *11, 11*. https://doi.org/10.3390/systems11110537.
6. Ahmed, T., Karmaker, C., Nasir, S., Moktadir, M., Paul, S. (2023). Modeling the artificial intelligence-based imperatives of industry 5.0 towards resilient supply chains: A post-COVID-19 pandemic perspective. *Computers and Industrial Engineering, 177*. https://doi.org/10.1016/j.cie.2023.109055.
7. Akundi, A., Euresti, D., Luna S., Ankobiah, W., Lopes, A., Edinbarough, I. (2022). State of Industry 5.0—Analysis and Identification of Current Research Trends. *Applied System Innovation, 5(1),* 27. https://doi.org/10.3390/asi5010027.
8. Aldea, A., Vaicekauskaite, E., Daneva, M., Piest, J. (2021). *Enterprise Architecture Resilience by Design: A Method and Case Study Demonstration.* Proceedings - IEEE International Enterprise Distributed Object Computing Workshop, EDOCW, 147-156. https://doi.org/10.1109/EDOCW52865.2021.00044.
9. Alves, J., Lima, T., Gaspar, P. (2023). Is Industry 5.0 a Human-Centred Approach? A Systematic Review. *Processes*, *11, 1*. https://doi.org/10.3390/pr11010193.
10. Andres, B., Diaz-Madronero, M., Soares, A., Poler, R. (2024). Enabling Technologies to Support Supply Chain Logistics 5.0. *IEEE Access, 12,* 43889-43906. https://doi.org/10.1109/ACCESS.2024.3374194.
11. Atif, A., Qureshi, M.A. (2024). Enhancing Digital Resilience through AI in Industry 5.0: A Technology Management Perspective, PICMET. *Portland International Conference on Management of Engineering and Technology (PICMET)*, pp. 1-9. https://doi.org/ 10.23919/PICMET64035.2024.10653227.
12. Atif, S. (2023). Analysing the alignment between circular economy and industry 4.0 nexus with industry 5.0 era: An integrative systematic literature review. *Sustainable Development*, *31/4,* 2155-2175, https://doi.org/10.1002/sd.2542.
13. Babkin, A., Shkarupeta, E., Kabasheva, I., Rudaleva, I., Vicentiy, A. (2022). A Framework for Digital Development of Industrial Systems in the Strategic Drift to Industry 5.0, *International Journal of Technology*, *13, 7,* 1373-1382, https://doi.org/10.14716/ijtech. v13i7.6193.
14. Bajaj, V., Kumar, P., Singh, V.K. (2022). Linkage dynamics of sovereign credit risk and financial markets: a bibliometric analysis. *Research in International Business and Finance 59,* 101566. https://doi.org/10.1016/j.ribaf.2021.101566.
15. Bakon, K., Holczinger, T., Sule, Z., Jasko, S., Abonyi, J. (2022). Scheduling Under Uncertainty for Industry 4.0 and 5.0. *IEEE Access, 10,* 74977-75017. https://doi.org/10.1109/ACCESS.2022.3191426.
16. Barata, J., Kayser, I. (2024). How will the digital twin shape the future of industry 5.0? *Technovation*, *134*, https://doi.org/10.1016/j.technovation.2024.103025.

17. Battini, D., Berti, N., Finco, S., Zennaro, I., Das, A. (2022). Towards industry 5.0: A multi-objective job rotation model for an inclusive workforce. *International Journal of Production Economics*, *250*. https://doi.org/10.1016/j.ijpe.2022.108619.
18. Berti, N., Finco, S., Guidolin, M., Battini, D. (2023). Towards Human Digital Twins to enhance workers' safety and production system resilience. *IFAC-PapersOnLine, 56/2,* 11062-11067. https://doi.org/10.1016/j.ifacol.2023.10.809.
19. Borchardt, M., Pereira, G., Milan, G., Scavarda, A., Nogueira, E., Poltosi, L. (2022). Industry 5.0 Beyond Technology: An Analysis Through the Lens of Business and Operations Management Literature. *Organizacija, 55/4,* 305-321. https://doi.org/10.2478/orga-2022-0020.
20. Braun, G., Rikala, P., Jrvinen, M., Hmlinen, R., Stahre, J. (2024). Bridging Skill Gaps - A Systematic Literature Review of Strategies for Industry. *Adv. Transdiscipl. Eng.*, *52*, 687-696. https://doi.org/10.3233/ATDE240209.
21. Breque, M., De Nul, L., Petridis, A. (2021). *Industry 5.0: Towards a Sustainable, Human-Centric and Resilient European Industry.* European Commission's Directorate-General for Research and Innovation, https://research-and-innovation.ec.europa.eu/knowledge-publications-tools-and-data/publications/all-publications/industry-50-towards-sustainable-human-centric-and-resilient-european-industry_en#files.
22. Callari, T., Vecellio Segate, R., Hubbard E., Daly, A., Lohse, N. (2024). An ethical framework for human-robot collaboration for the future people-centric manufacturing: A collaborative endeavour with European subject-matter experts in ethics. *Technology in Society*, *78*. https://doi.org/10.1016/j.techsoc.2024.102680.
23. Camarinha-Matos, L., Rocha, A., Grata, P. (2024). Collaborative approaches in sustainable and resilient manufacturing. *Journal of Intelligent Manufacturing*, *35/2*, 499-519, https://doi.org/10.1007/s10845-022-02060-6.
24. Castagnoli, R., Cugno, M., Maroncelli, S., Cugno, A. (2024). A New Research Agenda for Human-Centric Manufacturing: A Systematic Literature Review. *IEEE T. Eng. Manage., 71,* 15236-15253, https://doi.org/10.1109/TEM.2024.3479775.
25. Chabane, B., Komljenovic, D., Abdul-Nour, G. (2023). Converging on human-centred industry, resilient processes, and sustainable outcomes in asset management frameworks. *Environment Systems and Decisions*, *43/4,* 663-679, https://doi.org/10.1007/s10669-023-09943-w.
26. Chavez, Z., Gopalakrishnan, M., Nilsson, V., Westbroek, A. (2022). Exploring Data-Driven Decision-Making for Enhanced Sustainability. *Adv. Transdiscipl. Eng., 21,* 392-403. https://doi.org/10.3233/ATDE220158.
27. Cobo, M., López-Herrera, A., Herrera-Viedma, E., Herrera, F. (2011). Science mapping software tools: review, analysis, and cooperative study among tools. *J. Am. Soc. Inform. Sci. Technol., 62(7),* 1382-1402. https://doi.org/10.1002/asi.21525.

28. Corts-Leal, A., Crdenas, C., Del-Valle-Soto, C. (2022). Maintenance 5.0: Towards a Worker-in-the-Loop Framework for Resilient Smart Manufacturing. *Applied Sciences*, *12/22*. https://doi.org/10.3390/app122211330.
29. Dacre, N., Yan, J., Frei, R., Al-Mhdawi, M., Dong, H. (2024). Advancing sustainable manufacturing: a systematic exploration of Industry 5.0 supply chains for sustainability, human-centricity, and resilience. *Production Planning and Control*. https://doi.org/10.1080/09537287.2024.2380361.
30. Davim, J. (2025). Perceptions of Industry 5.0: Sustainability Perspective. *BioResources, 20/1,* 15-16. https://doi.org/10.15376/biores.20.1.15-16.
31. DeWit, A., Shaw, R., Djalante, R. (2020), An integrated approach to sustainable development, National Resilience, and COVID-19 responses: The case of Japan. *International Journal of Disaster Risk Reduction*, *Vol. 51,* 101808, https://doi.org/10.1016/j.ijdrr.2020.101808
32. Document 52024IE1285, Opinion of the European Economic and Social Committee – Industry 5.0 – how to make it happen (own-initiative opinion**)** EESC 2024/01285 EUR-Lex - 52024IE1285 - EN - EUR-Lex.
33. Domenteanu, A., Cibu, B., Delcea, C. (2024). Mapping the Research Landscape of Industry 5.0 from a Machine Learning and Big Data Analytics Perspective: A Bibliometric Approach. *Sustainability*, *16/7.* https://doi.org/10.3390/su16072764.
34. Erp, T., Carvalho, N., Gerolamo, M., Goncalves, R., Rytter, N., Gladysz, B. (2024). Industry 5.0: A new strategy framework for sustainability management and beyond. *Journal of Cleaner Production*, *461*. https://doi.org/10.1016/j.jclepro.2024.142271.
35. Foresti, R., Rossi, S., Magnani, M., Bianco, C.G.L., Delmonte, N. (2019). Smart Society and Artificial Intelligence: Big Data Scheduling and the Global Standard Method Applied to Smart Maintenance. *Engineering, 6(7),* 835-846. https://doi.org/10.1016/j.eng. 2019.11.014.
36. Fraga-Lamas, P., Fernández-Caramés, T., Rosado Da Cruz, A., Lopes S. (2024). An Overview of Blockchain for Industry 5.0: Towards Human-Centric. Sustainable and Resilient Applications. *IEEE Access, 12,* 11612-116201, https://doi.org/10.1109/ ACCESS. 2024.3435374.
37. Fraga-Lamas, P., Varela-Barbeito, J., Fernandez-Carames, T.M. (2021). Next Generation Auto-Identification and Traceability Technologies for Industry 5.0: A Methodology and Practical Use Case for the Shipbuilding Industry. *IEEE Access, Vol. 9*, pp. 140700-140730. https://doi.org/10.1109/ACCESS.2021.3119775.
38. Gal, B., Madreiter, T., Scheder, N., Liesinger, E., Hold, P., Schlund, S. (2024), Expanding the boundaries of Zero Defect Manufacturing - A systematic literature review. *Procedia CIRP, 122*, 336-341. https://doi.org/10.1016/j.procir.2024.01.050.
39. Gartner, Q., Ronco, E., Cagliano, A., Reinhart, G. (2023). Development of an Approach for the Holistic Assessment of Innovation Projects in Manufacturing Including Potential,

Effort, and Risk Using a Systematic Literature Review and Expert Interviews. *Applied Sciences, 13/5*. https://doi.org/10.3390/app13053221.

40. Ghobakhloo, M., Iranmanesh, M., Mubarak, M., Mubarik, M., Rejeb, A., Nilashi, M. (2022). Identifying Industry 5.0 Contributions to Sustainable Development: A Strategy Roadmap for Delivering Sustainability Values. *Sustainable Production and Consumption, 33*, 716-737. https://doi.org/10.1016/j.spc.2022.08.003.
41. Ghobakhloo, M., Mahdiraji, H., Iranmanesh, M., Jafari-Sadeghi, V. (2024). From Industry 4.0 Digital Manufacturing to Industry 5.0 Digital Society: a Roadmap Toward Human-Centric, Sustainable, and Resilient Production. *Information Systems Frontiers*. https://doi.org/10.1007/s10796-024-10476-z.
42. Golovianko, M., Terziyan, V., Branytskyi, V., Malyk, D. (2022). Industry 4.0 vs. Industry 5.0: Co-existence, Transition, or a Hybrid. *Procedia Computer Science*, *217*, 102-113, https://doi.org/10.1016/j.procs.2022.12.206.
43. Grabowska, S., Saniuk, S., Gajdzik, B. (2022). Industry 5.0: improving humanization and sustainability of Industry 4.0, *Scientometrics*, *127/6,* 3117-3144, https://doi.org/10.1007/ s11192-022-04370-1.
44. Gródek-Szostak, Z., Szeląg-Sikora, A., Siguencia, L., Niemczyk, A. (2023). From Industry 4.0 Paradigm Towards Industry 5.0, Vide. Tehnologija. *Resursi - Environment, Technology, Resources, 2,* 46-49. https://doi.org/10.17770/ etr2023vol2.7192.
45. Grosse, E., Sgarbossa, F., Berlin. C., Neumann, W. (2023). Human-centric production and logistics system design and management: transitioning from Industry 4.0 to Industry 5.0. *International Journal of Production Research*, *61/22,* 7749-7759. https://doi.org/10.1080/ 00207543.2023.2246783.
46. Haimes, Y.Y. (2009). On the definition of resilience in systems. *Risk Analysis: An International Journal*, *29/4*.
47. Hanaa, S.M., Abdul, A.P. (2023). A holistic approach to augmented reality-related research in tourism: through bibliometric analysis. *J. Hospitality Tourism Insights, 7(1),* 76-94. https://doiorg/101108/JHTI-08-2 022-0369.
48. Hansen, A., Christiansen, L., Lassen, A. (2024). Technology isn't enough for Industry 4.0: on SMEs and hindrances to digital transformation. *International Journal of Production Research*. https://doi.org/10.1080/00207543.2024.2305800.
49. Holling, C. (1973). Resilience and stability of ecological systems. *Annual review of ecology and systematics, 4(1)*, 1-23, http://dx.doi.org/10.24425/mper.2019.131443.
50. Huang, S., Wang, B., Li, X., Zheng, P., Mourtzis, D., Wang, L. (2022). Industry 5.0 and Society 5.0—Comparison, Complementation and co- Evolution. *Journal of Manufacturing Systems, 64*, 424-428. https://doi. org/10.1016/j.jmsy.2022.07.010.
51. Hunkova, L., Haviernikova, K. (2024), Exploring the intersection of strategic human resource management and Industry 5.0: a systematic literature review. *Entrep. Sustain., 12/1,* 25-35. https://doi.org/10.9770/jesi.2024.12.1(2).

52. Ismail, M., Ahmed. Z., Abdel-Gawad, A., Mohamed, M. (2024). Toward Supply Chain 5.0: An Integrated Multi-Criteria Decision-Making Models for Sustainable and Resilience Enterprise. *Decision Making: Applications in Management and Engineering, 7/1,* 160-186. https://doi.org/10.31181/dmame712024955.
53. Johansen, K., Akay, S. (2022). Emerging Technologies: Facilitating Resilient and Sustainable Manufacturing, *Adv. Transdiscipl. Eng., 21,* 751-767. https://doi.org/ 10.3233/ATDE220194.
54. Kaasinen, E., Anttila, A.-H., Heikkilä, P., Laarni, J., Koskinen, H., Väätänen, A. (2022). Smooth and resilient human-machine teamwork as an industry 5.0 Design Challenge. *Sustainability, 14(5),* 2773. https://doi.org/10.3390/su14052773.
55. Kaasinen, E., Anttila. A., Heikkil, P., Laarni. J., Koskinen, H., Vintnnen, A. (2022). Smooth and Resilient Human Machine Teamwork as an Industry 5.0 Design Challenge. *Sustainability, 14/5.* https://doi.org/10.3390/su14052773.
56. Kaz, K. (2019). Building Resilience into the Organization. In: R. Schmidpeter, N. Capaldi, S.O. Idowu, A. Stürenberg Herrera (eds.), International Dimensions of Sustainable Management. CSR. *Sustainability, Ethics & Governance* (pp. 69-87). Cham: Springer. https://doi.org/10.1007/978-3-030-04819-8_5.
57. Keenan, J.M., Trump, B.D., Hynes, W., Linkov, I. (2021). Exploring the convergence of resilience processes and sustainable outcomes in post-covid, post-glasgow economies. *Sustainability*, *13*(23), 13415; https://doi.org/10.3390/su132313415.
58. Kehrbusch, B., Engels, G. (2023). Digital Transformation-Towards Flexible Human-Centric Enterprises, *Digital Transformation: Core Technologies and Emerging Topics from a Computer Science Perspective*, 497-526. https://doi.org/10.1007/978-3-662-65004-2_20.
59. Kour, R., Karim, R., Dersin, P., Venkatesh, N. (2024). Cybersecurity for Industry 5.0: trends and gaps. *Frontiers in Computer Science*, *6.* https://doi.org/10.3389/fcomp. 2024.1434436.
60. Kulkarni, M.S., Patil, K. (2024). Managerial Competencies for Human Brains and Mechanical Muscles Interplay; A Study of Automotive Industries. In: S.K. Sharma, Y.K., Dwivedi, B. Metri, B. Lal, A. Elbanna (eds.), *Transfer, Diffusion and Adoption of Next-Generation Digital Technologies. TDIT 2023. IFIP Advances in Information and Communication Technology, vol. 699.* Cham: Springer, https://doi.org/10.1007/978-3-031-50204-0_6.
61. Kumareswaran, K., Jayasinghe, G. (2023). *Green Infrastructure and Urban Climate Resilience: An Introduction*, https://doi.org/10.1007/978-3-031-37081-6.
62. Lee, J., Siahpour, S., Jia, X., Brown, P. (2022). Introduction to resilient manufacturing systems. *Manufacturing Letters, 32*, pp. 24-27. https://doi.org/10.1016/j.mfglet. 2022.02.002.

63. Lei, Z., Shi, J., Luo, Z., Cheng, M., Wan, J. (2024), Intelligent Manufacturing From the Perspective of Industry 5.0: Application Review and Prospects. *IEEE Access, 12,* 167436-167451. https://doi.org/10.1109/ACCESS.2024.3496697.
64. Leirmo, T. (2024). Digital Twins for Industry 5.0: Unlocking the Human Potential. *IFAC-PapersOnLine, 58*, *27*, 761-766. https://doi.org/10.1016/j.procir.2024.10.161.
65. Leng, J., Chen, Z., Huang, Z., Zhu, X., Su, H., Lin, Z., Zhang, D. (2022). Secure Blockchain Middleware for Decentralized IIoT towards Industry 5.0: A Review of Architecture, Enablers, Challenges, and Directions. *Machines*, 10/10. https://doi.org/10.3390/machines10100858.
66. Lu, Y., Zheng, H., Chand, S., Bao, J. et al. (2022). Outlook on human-centric manufacturing towards Industry 5.0. *Journal of Manufacturing Systems, Vol. 62,* 612-627. https://doi.org/10.1016/j.jmsy.2022.02.001.
67. Marlow, E.C., Chmutina, K., Dainty, A. (2023). Interpreting sustainability and resilience in the built environment. *International Journal of Disaster Resilience in the Built Environment*, *Vol. 14, No. 3,* 332-348. https://doi.org/10.1108/IJDRBE-07-2021-0076.
68. Mazzoleni, M. (2024). Design of supervision solutions for industrial equipment: Schemes, tools and guidelines for the user. *Journal of Industrial Information Integration*, *41*. https://doi.org/10.1016/j.jii.2024.100667.
69. Moresi, M., Visioni, A., Cimini, A. (2024). A Cradle-to-Retailer Environmental Profile of Yellow Lentils (Lens culinaris ssp. Orientalis) as Such or Malted. *Appl. Sci-Basel, 14/23,* https://doi.org/10.3390/app142311207.
70. Mourtzis, D., Angelopoulos, J., Panopoulos, N. (2022a). A Literature Review of the Challenges and Opportunities of the Transition from Industry 4.0 to Society 5.0. *Energies*, *15/17,* https://doi.org/10.3390/en15176276.
71. Mourtzis, D., Angelopoulos, J., Panopoulos, N. (2022b). Operator 5.0: A Survey on Enabling Technologies and a Framework for Digital Manufacturing Based on Extended Reality. *Journal of Machine Engineering, 22(1),* 43-69. https://doi.org/10.36897/jme/147160.
72. Mourtzis, D., Angelopoulos, J. (2023). Development of an Extended Reality-Based Collaborative Platform for Engineering Education: Operator 5.0. *Electronics (Switzerland), 12/17.* https://doi.org/10.3390/electronics12173663.
73. Nourmohammadi, A., Fathi, M., Ng, A. (2022). Balancing and scheduling assembly lines with human-robot collaboration tasks. *Computers and Operations Research*, *140*. https://doi.org/10.1016/j.cor.2021.105674.
74. Omrany, H., Mehdipour, A., Oteng, D. (2024). Digital Twin Technology and Social Sustainability: Implications for the Construction Industry. *Sustainability*, *16/19.* https://doi.org/10.3390/su16198663.
75. Oztemel, E., Gursev, S. (2020). Literature review of Industry 4.0 and related technologies. *Journal of Intelligent Manufacturing*, *31(1),* 127-182.

76. Patalas-Maliszewska, J., Tosyk, H. (2024). Changes in Sustainable Development in Manufacturing in Cases of Unexpected Occurrences? *A Systematic Review, Sustainability (Switzerland), 16/2.* https://doi.org/10.3390/su16020717.
77. Prasad, D., Jayswal. S. (2019). Reconfigurable Manufacturing System - a New Class of Manufacturing System. *Management and Production Engineering Review*, *vol. 10, no. 4,* pp. 37-47.
78. Radid, A., Chakir, A., Ghazouani, M., Habib, B. (2024). Integrating Security into Industry 5.0: Challenges, Solutions, and Impacts. In: A. Chakir, R. Bansal, M. Azzouazi (eds.), Industry 5.0 and Emerging Technologies. *Studies in Systems, Decision and Control, vol. 565*. Cham: Springer. https://doi.org/10.1007/978-3-031-70996-8_13.
79. Rahmani, R., Jesus, C., Lopes, S. (2024). Implementations of Digital Transformation and Digital Twins: Exploring the Factory of the Future. *Processes*, *12/4.* https://doi.org/10.3390/pr12040787.
80. Rejeb, A., Rejeb, K., Zrelli, I., Kayikci, Y., Hassoun, A. (2024). The research landscape of industry 5.0: a scientific mapping based on bibliometric and topic modeling techniques. *Flex. Serv. Manuf. J.* https://doi.org/10.1007/s10696-024-09584-4.
81. Renda, A., Schwaag Serger, S., Tataj, D., Morlet, A. et al. (2021). *Industry 5.0, a transformative vision for Europe – Governing systemic transformations towards a sustainable industry.* European Commission: Directorate-General for Research and Innovation. Publications Office of the European Union, https://data.europa.eu/doi/10.2777/17322.
82. Resilience (2021). *Encyclopedia of Sustainable Management,* Resilience | SpringerLink.
83. Romero, D., Stahre, J. (2021). Towards the Resilient Operator 5.0: The Future of Work in Smart Resilient Manufacturing Systems. *Procedia CIRP*, *104*, 1089-1094. https://doi.org/10.1016/j.procir.2021.11.183.
84. Roostaie, S., Kouhirostami, M., Sam, M., Kibert, C.J. (2021). Resilience coverage of global sustainability assessment frameworks: A systematic review. *Journal of Green Building*, *16(2),* 23-53. https://doi.org/10.3992/jgb.16.2.23.
85. Roostaie, S., Nawari, N., Kibert, C.J. (2019). Sustainability and resilience: A review of definitions, relationships, and their integration into a combined building assessment framework *Building and Environment, Vol. 154,* 132-144, https://doi.org/10.1016/j.buildenv.2019.02.042.
86. Rose, A., Liao, S.Y. (2005). Modeling regional economic resilience to disasters: A computable general equilibrium analysis of water service disruptions. *Journal of regional science*, *45(1),* 75-112.
87. Safsten, K., Harlin, U., Johansen, K., Larsson, L., von Steyern, C.V., Ronnback, A.O. (2022). Towards Resilient and Sustainable Production Systems: A Research Agenda. *Adv. Transdiscipl. Eng.*, *21*, 768-780. https://doi.org/10.3233/ATDE220195.

88. Sambowo, A.L., Hidayatno, A. (2021). Resilience Index Development for the Manufacturing Industry based on Robustness, Resourcefulness, Redundancy, and Rapidity. *International Journal of Technology, Vol. 12(6),* 1177-1186. https://doi.org/10.14716/ijtech.v12i6.5229.
89. Saniuk, S., Grabowska, S., Straka, M. (2022). Identification of Social and Economic Expectations: Contextual Reasons for the Transformation Process of Industry 4.0 into the Industry 5.0 Concept. *Sustainability*, *14/3*. https://doi.org/10.3390/su14031391.
90. Sbaragli, A., Tomelleri, F., Picariello, F., Picariello, E., Pilati, F. (2024). Safe Operator 5.0 digital architecture: Towards resilient human-centric manufacturing systems. *IFAC-PapersOnLine, 58/19*, 265-270. https://doi.org/10.1016/j.ifacol.2024.09.187.
91. Seo, C., Yoo, D., Lee, Y. (2024). Empowering Sustainable Industrial and Service Systems through AI-Enhanced Cloud Resource Optimization. *Sustainability, 16, 12*. https://doi.org/10.3390/su16125095.
92. Sindhwani, R., Afridi, S., Kumar, A., Banaitis, A., Luthra, S., Singh, P. (2022). Can industry 5.0 revolutionize the wave of resilience and social value creation? A multi-criteria framework to analyze enablers. *Technology in Society*, *68*. https://doi.org/10.1016/j.techsoc.2022.101887.
93. Slavic, D., Marjanovic, U., Medic, N., Simeunovic, N., Rakic, S. (2024). The Evaluation of Industry 5.0 Concepts: Social Network Analysis Approach. *Applied Sciences*, *14, 3*. https://doi.org/10.3390/app14031291.
94. Suciu, M., Please, D.A, Petre, A., Simion, A., Mituca, M., Dumitrescu, D., Bocaneala, A., Moroianu, R., Nasulea, D. (2023). Core Competence? As a Key Factor for a Sustainable, Innovative and Resilient Development Model Based on Industry 5.0. *Sustainability*, *15, 9*. https://doi.org/10.3390/su15097472.
95. Sunmola, F., Baryannis, G. (2024). Artificial Intelligence Opportunities for Resilient Supply Chains. *IFAC-PapersOnLine, 58/19,* 813-818. https://doi.org/10.1016/j.ifacol. 2024.09.195.
96. Terziyan, V., Terziian, A., Vitko, O. (2024). Creative and Adversarial Cellular Automata for Simulating Resilience in Industry 5.0. *Procedia Computer Science*, *232*, 1491-1502. https://doi.org/10.1016/j.procs.2024.01.147.
97. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. (2021). *BMJ*, https://doi.org/10.1136/bmj.n71.
98. Thomassen, M., Henriksen, B. (2023). Resilience Maturity Assessment in Manufacturing Supply Chains. *Proceedings of the Conference on Production Systems and Logistics*, *vol. 5*, 947-956, https://doi.org/10.15488/15294.
99. Toth, A., Nagy, L., Kennedy, R., Bohus, B., Abonyi, J., Ruppert, T. (2023). The human-centric Industry 5.0 collaboration architecture. *Methodsx, 11*. https://doi.org/10.1016/ j.mex.2023.102260.

100. Verdugo-Cedeno, M., Jaiswal, S., Ojanen, V., Hannola, L., Mikkola, A. (2024). Simulation-Based Digital Twins Enabling Smart Services for Machine Operations: An Industry 5.0 Approach. *Int. J. Hum-Comput. Int.*, *40, 20*, 6327-6343. https://doi.org/10.1080/10447318.2023.2254607.
101. Villar, A., Paladini, S., Buckley, O. (2023). Towards Supply Chain 5.0: Redesigning Supply Chains as Resilient, Sustainable, and Human-Centric Systems in a Post-pandemic World. *Operations Research Forum*, *4, 3*. https://doi.org/10.1007/s43069-023-00234-3.
102. Vogus, T.J., Sutcliffe, K.M. (2007). Organizational resilience: Towards a theory and research agenda. *2007 IEEE International Conference On Systems, Man And Cybernetics*. IEEE, 3418-3422.
103. VOSviewer map and network files - VOSviewer Online Docs.
104. Vyhmeister, E., Castane, G. (2024). Towards industry 5.0 by incorporation of trustworthy and human-centric approaches, Artificial Intelligence in Manufacturing: Enabling Intelligent. *Flexible and Cost-Effective Production Through AI*, 361-379. https://doi.org/10.1007/978-3-031-46452-2_21.
105. Wachter, C., Beckschulte, S., Hinrichs, M., Sohnius, F., Schmitt, R. (2024). Strategies for Resilient Manufacturing: A Systematic Literature Review of Failure Management in Production. *Procedia CIRP*, 130,1393-1402. https://doi.org/10.1016/j.procir. 2024.10.257.
106. Wan, P., Leirmo, T. (2023). Human-centric zero-defect manufacturing: State-of-the-art review, perspectives, and challenges. *Computers in Industry*, *144*, https://doi.org/10.1016/j.compind.2022.103792.
107. Wolniak, R. (2023). Industry 5.0 - Characteristic, Main Principles, Advantages and Disadvantages. *Zeszyty Naukowe Organizacja i Zarządzanie, no. 170*. Politechnika Śląska.
108. Yang, J., Liu, T., Liu, Y., Morgan, P. (2022). Review Of Human-Machine Interaction Towards Industry 5.0: Human-Centric Smart Manufacturing. *Proceedings of the ASME Design Engineering Technical Conference, 2*. https://doi.org/10.1115/DETC2022-89711.
109. Yitmen, I., Almusaed, A., Alizadehsalehi, S. (2023). Investigating the Causal Relationships among Enablers of the Construction 5.0 Paradigm: Integration of Operator 5.0 and Society 5.0 with Human-Centricity, Sustainability, and Resilience. *Sustainability-Basel*, 15-11. https://doi.org/10.3390/su15119105.
110. Zeb, S., Mahmood, A., Khowaja, S., Dev, K., Hassan, S., Gidlund, M., Bellavista, P. (2024). Towards defining industry 5.0 vision with intelligent and softwarized wireless network architectures and services: A survey. *Journal of Network and Computer Applications*, *223*. https://doi.org/10.1016/j.jnca.2023.103796.

Appendix 1

Analysis of the phrase "resilience in Indusrty 5.0" by most common areas

Areas linking to "resilience"	Authors papers
Sustainability	Abdous et al. (2023), Afzal et al. (2024), Agote-Garrido et al. (2023), Ahmed et al. (2023), Aldea et al. (2021), Alves et al. (2023), Andres et al. (2024), Atif (2023), Babkin et al. (2022), Barata, Kayser, (2024), Battini et al. (2022), Borchardt et al. (2022), Callari et al. (2024), Camarinha-Matos et al. (2024), Camarinha-Matos et al. (2024), Camarinha-Matos et al. (2024), Castagnoli et al. (2024), Chabane et al. (2023), Chavez et al. (2022), Chavez et al. (2022), Cortés et al. (2022), Dacre et al. (2024), Domenteanu et al. (2024), Erp et al. (2024), Fraga-Lamas et al. (2024), Gal et al. (2024), Ghobakhloo et al. (2024), Grabowska et al. (2022), Gródek-Szostak et al. (2023), Hansen et al. (2024), Ismail et al. (2024), Kehrbusch, Engels, (2023), Kour et al. (2024), Lei et al. (2024), Leirmo (2024), Mourtzis et al. (2022), Nourmohammadi et al. (2022), Omrany et al. (2024), Patalas-Maliszewska, Łosyk, (2024), Rahmani et al. (2024), Rejeb et al. (2024), Säfsten et al. (2022), Saniuk et al. (2022), Sindhwani et al. (2022), Suciu et al. (2023), Verdugo-Cedeno et al. (2024), Vyhmeister, Castane (2024), Wan, Leirmo (2023), Yang et al. (2022), Yitmen et al. (2023), Zeb et al. (2024).
Human-centric	Abdous et al. (2023), Abuhasel (2023), Afzal et al. (2024), Agote-Garrido et al. (2023), Ahmed et al. (2023), Aldea et al. (2021), Alves et al. (2023), Andres et al. (2024), Atif (2023), Babkin et al. (2022), Babkin et al. (2022), Barata, Kayser (2024), Battini et al. (2022), Berti et al. (2023), Borchardt et al. (2022), Braun et al.(2024), Callari et al.(2024), Camarinha-Matos et al. (2024), Castagnoli et al. (2024), Chabane et al. (2024), Cortés-Leal et al. (2022), Dacre et al. (2024), Domenteanu et al. (2024), Erp et al. (2024), Fraga-Lamas et al. (2024), Gal et al. (2024), Gärtner et al. (2023), Ghobakhloo et al. (2022), Grabowska et al. (2022), Grosse et al. (2023), Gródek-Szostak et al. (2023), Hansen et al. (2024), Hunkova, Haviernikova, (2024), Ismail et al. (2024), Kaasinen et al. (2022), Kehrbusch, Engels (2023), Kour et al. (2024), Lei et al. (2024), Leirmo, (2024), Mourtzis, Angelopoulos, (2023), Mourtzis et al. (2022), Nourmohammadi et al. (2022), Patalas-Maliszewska, Łosyk (2024), Rahmani et al. (2024), Rejeb et al. (2024), Romero, Stahre (2021), Sbaragli et al. (2024), Suciu et al. (2023), Villar et al. (2023), Vyhmeister, Castane (2024), Wan, Leirmo (2023), Yang et al. (2022), Yitmen et al. (2023), Zeb et al. (2024).
Collaboration human-machine	Alves et al. (2023), Babkin et al. (2022), Barata, Kayser, (2024), Battini et al.(2022), Borchardt et al. (2022), Braun et al. (2024), Callari et al. (2024), Camarinha-Matos et al. (2024), Castagnoli et al. (2024), Domenteanu et al. (2024), Golovianko et al. (2022), Grosse et al. (2023), Gródek-Szostak et al. (2023), Hansen et al. (2024), Hunkova, Haviernikova, (2024), Ismail et al. (2024), Kaasinen et al. (2022), Kour et al. (2024), Leng et al. (2022), Mazzoleni (2024), Mourtzis, Angelopoulos (2022), Nourmohammadi et al. (2022), Rahmani et al. (2024), Rejeb et al. (2024), Romero, Stahre (2021), Säfsten et al. (2022), Sbaragli et al. (2024), Sindhwani et al. (2022), Slavic et al. (2024), Sunmola, Baryannis, (2024), Terziyan et al. (2024), Toth et al. (2024), Villar et al. (2023), (2024), Wachter et al. (2024), Wan, Leirmo, (2023), Yang et al. (2022).
Technology Integration	Abuhasel (2023), Afzal et al. (2024), Agote-Garrido et al. (2023), Aldea et al. (2021), Andres et al. (2024), Atif S. (2023), Babkin et al. (2022), Barata, Kayser, (2024), Berti et al. (2023), Cortés-Leal et al. (2022), Dacre et al. (2024), Erp et al. (2024), Gärtner et al. (2023), Golovianko et al. (2022), Grosse et al. (2023), Hansen et al. (2024), Hunkova, Haviernikova, (2024), Ismail et al. (2024), Johansen, Akay (2022), Kaasinen et al. (2022), Kehrbusch, Engels (2023), Kour et al. (2024), Lei et al. (2024), Leirmo (2024), Leng et al. (2022), Mazzoleni (2024), Mourtzis, Angelopoulos, (2022), Nourmohammadi et al. (2022), Omrany et al. (2024), Patalas-Maliszewska, Łosyk (2024), Rahmani, Jesus, Lopes, (2024), Rejeb et al. (2024), Romero, Stahre (2021), Säfsten et al. (2022), Saniuk et al. (2022), Sbaragli et al. (2024), Seo et al. (2024), Sindhwani et al. (2022), Slavic et al. (2024), Suciu et al. (2023), Terziyan et al. (2024), Verdugo-Cedeno et al. (2024), Villar et al. (2023), Vyhmeister, Castane, (2024), Wachter et al. (2024), Wan, Leirmo, (2023), Yitmen et al. (2023), Zeb et al. (2024).

Ability to adapt	Abuhasel (2023), Ahmed et al. (2023), Andres et al. (2024), Atif (2023), Babkin et al. (2022), Battini et al. (2022), Berti et al. (2023), Braun et al. (2024), Callari et al. (2024), Castagnoli et al. (2024), Chabane et al. (2023), Cortés-Leal et al. (2022), Dacre et al. (2024), Erp et al. (2024), Gal et al. (2024), Gärtner et al. (2023), Golovianko et al. (2022), Grabowska et al. (2022), Grosse et al. (2023), Gródek-Szostak et al. (2023), Hansen et al. (2024), Hunkova, Haviernikova (2024), Ismail et al. (2024), Johansen, Akay (2022), Kaasinen et al. (2022), Kehrbusch, Engels (2023), Kour et al. (2024), Mourtzis, Angelopoulos, (2023), Nourmohammadi et al. (2022), Omrany et al. (2024), Patalas-Maliszewska, Łosyk, (2024), Rahmani et al. (2024), Rejeb et al. (2024), Romero D.; Stahre J. (2021), Säfsten et al. (2022), Saniuk et al. (2022), Sbaragli et al. (2024), Seo et al. (2024), Sindhwani et al. (2022),(2022), Slavic et al. (2024), Suciu et al. (2023), Sunmola, Baryannis (2024), Terziyan et al. (2024), Toth et al. (2023), Verdugo-Cede?o et al. (2024), Villar et al. (2023), Vyhmeister, Castane, (2024), Wachter et al. (2024), Wan, Leirmo, (2023), Yang et al. (2022), Yitmen et al. (2023), Zeb et al. (2024).
Supply chain flexibility	Ahmed et al. (2023), Andres et al. (2024), Barata, Kayser (2024), Camarinha-Matos et al. (2024), Chavez et al. (2022), Cortés-Leal et al. (2022), Dacre et al. (2024), Fraga-Lamas et al. (2024), Ismail et al. (2024), Patalas-Maliszewska, Łosyk (2024), Säfsten et al. (2022), Saniuk et al. (2022), Villar et al. (2023).
Risk management	Aldea et al. (2021), Borchardt et al. (2022), Chabane et al. (2023), Cortés-Leal et al. (2022), Ismail et al. (2024), Sunmola, Baryannis (2024).

Source: Authors' elaboration.

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DUALISTIC MODEL OF THINKING AND LEADERSHIP PREDISPOSITIONS AMONG EXECUTIVES

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Purpose: This paper attempts to identify the relationship between the dualistic cognitive model and the intensity of the leadership quotient and also the link between rationality and leadership predispositions.
Design/methodology/approach: The article is based on empirical research using questionnaires to measure the dualistic cognitive model (TRM) and leadership predisposition (LQ), in other words, it is grounded in data obtained from a control research group and statistical analysis. This was possible thanks to a comparative analysis of managers and subordinates in the studied organization. The subject area relates to human resource management and cognitive psychology.
Findings: A dualistic cognitive model was found to be related to leadership predisposition and that higher levels of impulsivity were related to the leadership quotient. On this basis, it can be assumed that effective managers have dominant fast thinking, which indicates an important phenomenon in management.
Research limitations/implications The research focused on the SME sector, so the results may be specific to this sector and the sample was relatively small and this is a kind of limitation that makes the research conducted exploratory and preliminary. In the future it would be advisable to conduct a longitudinal study and increase the research sample and see how the research would fare in different cultures and organizational environments.
Practical implications: The results of the research can also be used to develop recruitment tools that take into account impulsivity as an important factor to assess the potential of managers. On the basis of the findings, a new style of building management teams can be developed in organizations where different thinking styles of managers can complement each other. Companies can take into account the cognitive abilities of managers in their development processes and thus gain a competitive advantage through a more effective management team.
Originality/value: The article is the first to make the connection between the dualistic model of thinking and the leadership predisposition of managers. It provides the first research on the correlation of impulsivity, with a high leadership quotient. This in turn shows what kind of people can be better managers and this article is an answer to the question of whether issues related to their cognitive functions translate into leadership predispositions and, consequently, effective management. This provides an important rationale for further analysis in this area.
Keywords: dualistic model of thinking, leadership aptitude, leadership quotient, executives.
Category of the paper: empirical and scientific research.

1. Introduction

Leadership is reflected in both private and professional life in every aspect, and can even be considered the driving force behind the coexistence of people in general. It is particularly desirable in business, where in organizations it is necessary to supervise the course of processes and continuously give direction to activities and undertakings. This thesis aims to illustrate the relationship between the intensities of traits such as, impulsivity and rationality in the subject of leadership predisposition. In order to become a manager and be able to manage an organization, one must have the necessary competences and skills to do so, including personality predispositions. Managers lead the other employees and set the rhythm for the whole enterprise. It can therefore be said that managers are leaders in an organization. However, not everyone is suited to be a leader. Certain characteristics predispose one to take on such a role. And it is impulsiveness and rationality that seem to matter, as they are crucial during the decision-making process that is indispensable in management. The question therefore arises as to whether managers who are more impulsive or more rational are more predisposed to leadership. The literature suggests that a high degree of rationality, i.e. a dominant slow-thinking style, is a facilitator of career success (Assuad, 2020), so the assumption has been made that rationality may also be related to leadership aptitude.

2. Essence and significance of the dualistic model of thinking

Reflexivity as understood in cognitive psychology is seen primarily as a construct of the individual and is understood quite differently from management. According to Kagan's conception, reflexivity is the slow consideration and response to a problem. Impulsivity, on the other hand, is based on reacting violently and acting without much thought (Kaufmann, Meschnig, Reimann, 2014). This construct was also taken up by Kahneman in his reflections and he proved that the perception of reality takes place by reacting with one of two cognitive systems. Based on this, he developed a dualistic model of thinking that differentiates people in terms of reacting and making judgements (Gasparski, 2016). Kahneman distinguished between two systems, where the first, is characterized by fast thinking and is also referred to by the term impulsivity. It operates automatically and subconsciously, without volitional input. And the second system, which is related to slow thinking and is called rationality. This one, on the other hand, operates consciously and requires the involvement of different cognitive spheres, and this in turn carries more cognitive effort. The two modes operate continuously and interact with each other. System one triggers suggestions for system two, and this influences what beliefs the slow thinking system will hold. Conversely, fast thinking, if it is resolving

a complex situation supports its actions by building on what has already been established through slow thinking (Kahneman, 2019). The author's model is shown in Figure 1.

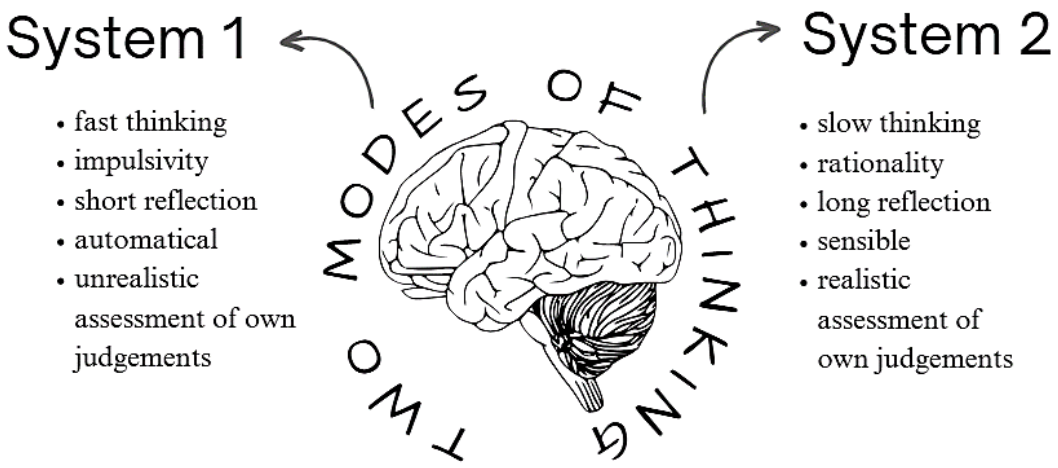

Figure 1. Dualistic model of thinking.

Source: own based on Kahneman, Szymczak, Tversky, p. 15.

If impulsivity predominates in an individual then the response to external and internal stimuli will be involuntary and abrupt. This is directly related to thoughtlessness, and the presence of it results in low sensitivity to the consequences of that individual's actions. The opposite is true for dominant rationality, as it goes hand in hand with reflexivity and a sense of responsibility for the choices made (Strang, 2023). The two systems coexist and can operate alternately with the meaning that one of them will manifest itself more frequently (Claverie, Trinquecoste, 2024). Impulsive people have it in their nature to make an immediate decision without deep thought, whereas rational people are much more calm and methodical in their actions. Therefore, their judgements and decisions are made after a long reflection. Thus, managers can be different and their specific performance depends on which cognitive system prevails in them (Zhang, 2023). It is also worth noting that slow thinking can impinge on the long-term perspective of an organization, while fast thinking allows for solving current problems without much consideration of the future implications of that action (Assuad, 2020). The dual model of thinking differentiates all people in terms of how they respond to incoming information (Claverie, Trinquecoste, 2024). The meticulousness and determination with which individuals with dominant slow thinking deal with problem situations makes them less likely to succumb to cognitive errors (Kurdoglu, Lerner, Ates, 2020). Although, if one chooses to take into account the ability to make decisions and judgements, when dealing with situations and concepts that are new and with which the individual has never been familiar, people with predominantly fast thinking adapt much better and more easily and have a higher propensity to take risks. Which in a company can also be beneficial (Borchert, 2025).

The dualistic model of interpreting events boils down to how we react and analyse incoming impulse. Rationality is closely linked to deduction and impulsivity to induction. What particular system dominates in someone determines what kind of person they are. So, since there is such

a distinction between impulsive and rational people, managers can also be classified in this way. And undoubtedly, some system will prevail among executives. The first of these dimensions relates to affect and emotional balance, which allows for action. The second area relates to perception and cognitive abilities, i.e., among other things, it is responsible for the ability to learn and reason. And the last relates to effort and productivity and is reflected in the ability to set and achieve goals and objectives.

3. Importance and role of leadership aptitude in management

Leadership aptitude is a very broad construct encompassing the entire marriage of an individual's qualities and skills. Therefore, in order to understand the essence and role of this issue, it is necessary to consider the whole range of approaches to it, in order to convey, relatively speaking, its meaning as best as possible. The overriding goal of a company is to achieve a competitive advantage, and this is not possible when management lacks leadership aptitude. The course of processes is a product of the influence of management (Hensellek et al., 2023). The leadership aptitude of managers is of considerable importance in relation to the functioning of the entire enterprise. Therefore, it is important to understand what factors are their components. Furthermore, it should be borne in mind that, depending on the authors and treatment, leadership aptitude will consist of different characteristics, as it is a multidimensional construct and difficult to define precisely (Güttel, Kleinhanns-Rollé, 2021). In general, leadership predispositions are mainly abilities and skills rooted in temperamental, personality and cognitive aspects (Kraczla, 2013). These include skills in communication, conflict management, and self-motivation (Zada et al., 2023). Solaj claims a sense of control, a sense of agency, authoritarianism, achievement pressure, Machiavellianism intrinsic controllability and self-evaluation skills as the traits that make up leadership aptitude (2011, after Mai et al., 2022). Further components are personality determinants such as charisma or temperament. And from these, further ones are derived, such as the need for affiliation, a sense of power or pressure to achieve (Zulaikha, 2022). Empathy, self-awareness speed of reaction, self-reflection, and insight are also factors that make up leadership aptitude (Groes, Nørmark, 2024). Also worth mentioning are, aspects such as intelligence, motivation and cognitive ability (Kraczla, 2013). Properties such as interpersonal communication, erudition, high eloquence, creativity, ability to work under stress, commitment, desire for self-improvement, openness, winning over others, creating a vision, skills are also factors that fall into this spectrum (Van Dick, Fink, 2019).

As can be seen from the above considerations, the psychological phenomena and components of leadership predisposition are many, so it has been proposed to frame leadership predisposition as a *leadership quotient*, where it should be understood as an integrated propensity to lead, based on three fundamental dimensions. Accordingly, everyone manifests

these resources but, importantly, those who have an aptitude for leadership are distinguished not only by a balanced coordination of these components, but also by their relative equality. According to this manifestation, all manifestations of leadership aptitude relate precisely to these three dimensions (Mazumdar, Mukhopadhyay, 2012). If one of these dimensions is too highly developed in a manager, there may be communication problems with subordinate staff. The same is true if any of the dimensions are underdeveloped. For example, if a manager presents low resources in the context of emotional balance, he or she will be easily manipulated (Reinisch, 2019). Below is a visualization of this model in Figure 2.

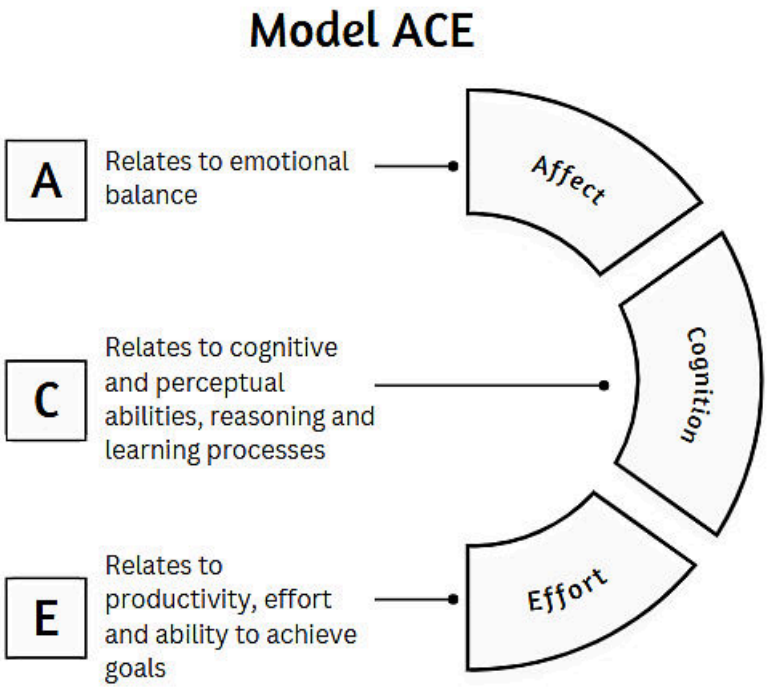

Figure 2. Dimensions of the ACE model.

Source: own based on: Mazumdar, Mukhopadhyay, pp. 2-3.

This is crucial, as it is the personal resources that individuals possess that are of paramount importance in terms of achieving organizational success. This is particularly relevant for managers, as they are responsible for giving direction not only to the company in general, but also to the rest of the workforce. Without the right leadership aptitude, they will lack authority and, as a consequence, the organizational mission and goals will not be fulfilled (Güttel, Kleinhanns-Rollé, 2021).

The essence of leadership predisposition is difficult to capture uniformly, due to the multifactorial nature of these factors. Nevertheless, it is clear that cognitive functions are an important distinction in this respect. Thus, a link between impulsivity and rationality and leadership aptitude is not excluded. Since cognitive factors are mentioned in the literature in the context of leadership predisposition, it is possible that the way one reacts to a problem may be another determinant of this.

4. Relationship of the dualistic model of thinking to managers' leadership predispositions

Supervision and control of the activities taking place in a company would not be possible without the appropriate skills and competences of managers. Key in this respect appear to be the ability to lead others. As we know, this consists, among other things, of individual cognitive factors such as intelligence or the ability to learn, so the question arises as to whether the intensity of impulsivity-rationality, is a factor included in leadership aptitude. And if so, which cognitive system is the component that determines leadership aptitude.

There are indications in the literature from which this link can be surmised. If one were to look at the issue in terms of, temperament and risk-taking propensity, which have been proven to make up leadership predispositions, this can be linked to the ability to manage risk and to the way risk is interpreted (2010, after Kraczla, 2013). Since it is clear that rational people are risk-averse and impulsive people the opposite (Swoboda, Schramm-Klein, 2025) then perhaps the way they are perceived differentiates them. If the creation of a logical argument is taken to task, those with predominantly fast thinking will be more creative, but those with predominantly slow thinking will commit less frequent succumbing to heuristics (Rożnowski, Fortuna, 2020). The views and mindset presented determine a kind of way, or style, of leading employees in an organization (Farrukh et al., 2023). According to it, it is the individualism of the individual in terms of perceiving reality that determines success in the decision-making process (Farrukh et al., 2023), moreover, if we take the ACE model into account in these considerations, we can see that the authors pay attention to the cognitive dimension, which is supposed to centre around the individual's ability to learn and understand the surrounding reality. This suggests that the construct of a dualistic perceptual model may also be related to leadership predispositions (Saint-Michel, 2023).

To this it is worth mentioning that, the phenomenon of the dualistic model of interpreting events can also be taken up in the context of leadership style. The assumption is that slow thinking occurs in a rational leader, while impulsive thinking occurs in an impulsive one. The thinking system determines a certain tendency to lead and is thus a component of leadership (Strang et al., 2023). Based on this, a distinction can be made between an impulsive leader, who is better at handling new situations, and a rational leader, who is better at planning strategies (Rożnowski, Fortuna, 2020). In addition, most of the research conducted in the rationality-impulsivity direction indicates that rational people do better in life (Trost, 2022). Therefore, on this basis, it seems more likely that it is rationality that is associated with leadership predisposition. It has already been proven that cognitive functions such as levels of crystallized intelligence and fluid intelligence are positively correlated with leadership aptitude (Saint-Michel, 2023). So, one can make the assumption that if certain cognitive functions are linked to leadership predispositions then presumably the dualistic model of thinking is as well. Thus, this argument leads to the formulation of two research hypotheses, namely:

1. *The dualistic cognitive model is related to leadership predispositions in executives.*
2. *The dominant intensity of rationality is related to the leadership predisposition of managers.*

Despite providing a great deal of reflection and research on issues such as personality determinants in relation to leadership predisposition, the question of cognitive function and leadership predisposition still remains largely a matter of conjecture. The question therefore arises as to whether there is a relationship between leadership aptitude and the Kahneman model, as well as whether rationality positively correlates with leadership.

5. Methodology

Two tools were used to verify the hypotheses. The first tool was the *Test Refleksyjności Myślenia/ Reflective Thinking Test* (TRM), developed by Piotr Gasparski. It is a questionnaire that measures the severity of the impulsivity-rationality variable and is based on Kahneman's dualistic model of thinking, with impulsivity and rationality to be understood as one variable and as two opposite ends of one continuum (Gasparski, 2016). The TRM is an extension of Frederic's CRT test, which was designed to assess judgement and served as a pioneering tool for this. The *Cognitive Refection Test* (CRT) was a questionnaire readily used in management science, marketing and, of course, psychology, however, over time its measurement errors have been identified (Szydłowski, 2015). Therefore, it needed to be revalidated to meet standards and standardization. For this reason, Gasparski developed a second version of this test, the *Test Refleksyjności Myślenia* (TRM), which is a set of logical riddles that measure the level of reflexivity and impulsivity, in other words, verifying which thinking system dominates in the subject, whether the one based on slow thinking or the one based on fast thinking (Gasparski, 2016).

The second tool used for this article was the *Leadership Quotient* (LQ), a questionnaire that is based on the ACE model by Mazumdar and Mukhopadhyay, measuring leadership aptitude (Mazumdar, Mukhopadhyay, 2012). The LQ questionnaire consists of 40 questions and 3 scales and can differentiate between subjects in terms of having a leadership predisposition, but also in terms of the dimensions that comprise it (Reinisch, 2019). The relationships are shown below in Figure 3. In order to be able to demonstrate leadership predisposition in the respondent, the scores obtained on all scales should be relatively equal. Therefore, in order to recognize a leadership predisposition in the respondent, all dimensions should be developed at a similar level. Importantly, if one is higher then the others should be lower (Mazumdar, Mukhopadhyay, 2012).

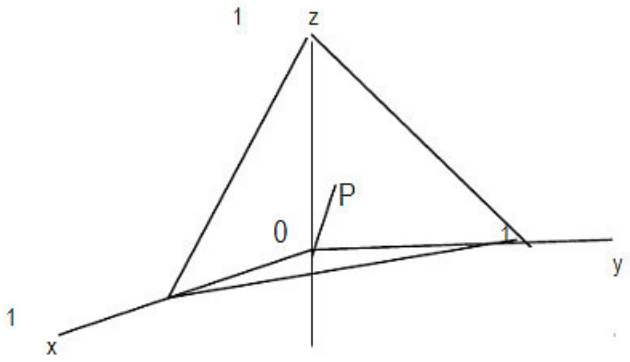

Figure 3. Assumptions of the ACE model.

Source: Mazumdar, Mukhopadhyay, p. 4.

According to the assumptions, the dimensions should satisfy the condition A + C + E =1.

That is, the results from scales A, C and E should be such that they are closest to the centre of the plane of the triangle; in other words = $[x^2+ y^2+ z^2]^{1/2}$ should be the minimum. The LQ assumes that in order to show leadership predisposition, scores from the scales should be A ≈ 0.33, C ≈ 0.33, E ≈ 0.33 (Mazumdar, Mukhopadhyay, 2012).

Both of these questionnaires were used in surveying 100 people across a dozen SME companies, where half were the research group and the other half the control group. The study group consisted of executives, i.e. people in the positions of presidents, directors, managers and coordinators. The control group, on the other hand, consisted of staff members reporting to them. Age, education, material status and gender are varied. The other parameters were not controlled. The dependent variable is leadership aptitude and the independent variable is impulsivity-rationality. As for the test procedure, separate rooms were set up so that there were as few distractions as possible and people were asked to complete both questionnaires. The duration of the test was arbitrary, the selection of people for the survey was relatively homogeneous.

6. Research results

To verify the hypotheses, an analysis of the collected empirical data was carried out using *Statistica 13.3* and *Jamovi*. For clarification purposes, the results obtained were averaged for the variables impulsivity-rationality and leadership quotient. What is shown in table 1 and 2. Due to the heterogeneity of the distributions, Pearson correlation was used to verify the relationship between the variables.

Table 1.
Pooled summary of averaged results from the TRM for the test and control group

	TRM		
	impulsivity	**rationality**	Total
research group	10,05	8,20	9,85
control group	8,35	9,95	8,97

Source: own elaboration based on Statistica 13.3.

Table 2.
A summary of the averaged results from the LQ for the test and control group

	ACE			
	[A] affect dimension	**[C] cognitive dimension**	**[E] effort dimension**	**LQ**
research group	0,37	0,44	0,31	1,03
control group	0,78	0,26	0,11	0,54

Source: own elaboration based on Statistica 13.3.

The averaged results from the TRM questionnaire showed clear differences between the research group and the control group, namely that managers are defined by a high degree of impulsivity, as opposed to subordinates, in whom rationality predominates. In other words, there was a greater tendency towards fast thinking in the research group and slow thinking in the control group. This highlights that managers are characterized by the dominance of the first cognitive system. On the other hand, the averaged results from the LQ questionnaire clearly showed that the research group had a leadership predisposition. In view of the above, the managers surveyed possessed leadership predispositions and were characterized by impulsiveness. It is also worth, noting the Pearson correlation, shown in figure 4 and table 3 showing correlation values between TRM and LQ.

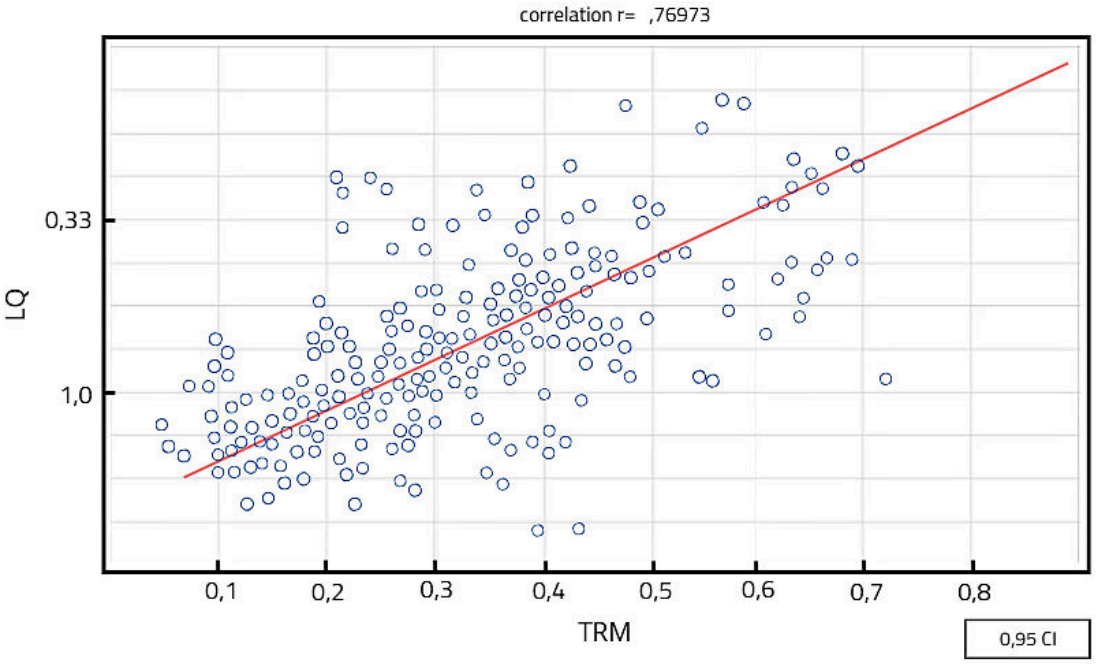

Figure 4. Pearson correlation for TRM and LQ variables.

Source: own elaboration based on results from *Jamovi*.

Table 3.
Correlation values between TRM and LQ variables

		TRM	LQ
TRM	r	1	-,769**
	p		<,05
	N	100	100
LQ	r	-,769**	1
	p	<,05	
	N	100	100

where p = twosided significance
** Statistically significant correlation

Source: own elaboration based on results from *Jamovi.*

The Pearson correlation graph shows a clear upward trend, that is, the higher the TRM value the higher the LQ value. This shows that there is a relationship between the variables. The confidence interval is 0.95, indicating a strong and positive relationship. The correlation coefficient (r = 0.769) is close to 1, indicating the presence of a very strong correlation between leadership aptitude and impulsivity. The correlation obtained is statistically significant ($p < 0.05$) which also confirms the association of the variables. Hypothesis one was confirmed.

7. Discussion

Through this discourse, concerning the relationship between the dualistic model of thinking and leadership predispositions, new conclusions have been grasped in this respect. The dualistic cognitive model was found to be related to leadership predisposition. Significantly, the literature opined explicitly that it was rationality that would be associated with leadership predisposition. However, the analysis of empirical studies has shown that this higher intensity of impulsivity is related to the leadership quotient.

The fact that the dualistic model of thinking is linked to the occurrence of leadership predispositions seems to be a kind of logical corollary, since the ACE model consists of a cognitive dimension into which thinking systems can fit. In contrast, the predominant impulsivity in managers is surprising. Since the majority of managers were rational in previous studies conducted it was considered that apparently rationality is related to leadership predisposition. And rationality seemed to be one of the components of leadership predispositions. Therefore, this article disproves this belief.

The explanation for this seems to be other research in this area. Well, one of the most recent studies, promotes an impulsive style and emphasizes its measurable effects in new problem situations, as such employees are perceived as more productive from the employer's point of view. In addition, decision-makers with dominant fast thinking are braver and find themselves much better in chaos and difficult situations, and are more successful in day-to-day problem solving, compared to rational decision-makers (Smith et al., 2023). In addition, they are much

more creative and have unconventional thinking, which supports the continuous development of the organization (Elliott et al., 2022). It seems that this variability in both the organization and its environment is a factor in why fast thinking is conditioned in managers. Perhaps the link between impulsivity and risk-taking propensity is the reason, since leadership propensity consists of the ability to take risks, and it also goes hand in hand with impulsivity *per se*, this could potentially be the reason why impulsivity is linked to the leadership quotient. In addition, temperament and charisma may also be directly related to impulsivity. There is certainly still much scope for scientific exploration.

Nonetheless, the research conducted leads to the conclusion that there is a clear link between the dualistic model of thinking and leadership predisposition. Managers showing a leadership predisposition also show at the same time a dominance of the first cognitive system based on fast thinking. In other words, managers with a leadership predisposition are impulsive. This provides an important rationale for further analysis in this area.

8. Summary

The empirical objective of the article was to verify the relationship between rationality of thinking and the occurrence of leadership predisposition in managers. People, can be differentiated on the basis of a dualistic cognitive model, namely into rational, that is, with a predominantly fast mode of thinking, and impulsive, with a predominantly slow mode of thinking. On the back of this discourse, the hypothesis was formed that managers with a high degree of rationality also have a greater leadership predisposition. To verify this hypothesis, a questionnaire study was conducted using the *Reflective Thinking Test* (TRM) and the *Leadership-Quotient* (LQ) with a total of 100 employees divided into a research and control group, i.e. managers and their subordinates respectively. The data collected was analysed using Pearson's correlation. The results led to the conclusion that leadership predisposition is related to high levels of impulsivity among managers. The results obtained from this work can be useful both in the context of human resource management of team building and in the formation of managers themselves. In particular, they can help in the appropriate selection of managers and thus contribute to more effective management of organizations. It can also provide a certain starting point. In recruitment processes where impulsiveness and rationality can be traits that indicate leadership skills that may be desirable for key positions. For this, too, it would be useful, for example, to use decision-making scenarios a in order to see how impulsive leaders perform in business management. For this, specific methods and tools such as, for example, In-basket, Behavioral and Situational Interviews or Assessment Center can be used (Boyle, 2016). These methods can be extended to the studied factor the way to get better results. It certainly provides an important premise for further research as well as for using the information obtained for the personal development of managers.

References

1. Assuad, C. (2020). Understanding Rationality in Sustainable Development Decision-Making: Unfolding the Motivations for Action. *J. Knowl. Econ., 11*, 1086-1119, p.7.
2. Borchert, M. (2025). Herleitung des psycho-ökonomischen Verhaltensmodells. *In People Management: Eine psycho-ökonomische Perspektive: Theorien–Modelle–Praxis*. Berlin/Heidelberg: Springer, pp. 27-29.
3. Boyle, S. (2016). Influencing Decisions About Assessment and Development Centres for Talent Management. *Assessment Centres and Global Talent Management*, 299-313.
4. Claverie, B., Trinquecoste, J.F. (2024). Guerre cognitive et influence psychologique. *Ingénierie cognitique*, *7(1),* pp. 47-56.
5. Elliott, M., Johnson, S., Pearlstein, J., Lopez, D., Keren, H. (2022). Emotion-related impulsivity and risky decision-making: A systematic review and meta-regression. *Clinical Psychology Review*, *102232*, p. 15.
6. Farrukh, M., Raza, A., Rafiq, M. (2023). Environmentally specific authentic leadership and team green creative behavior based on cognitive-affective path systems. *International Journal of Contemporary Hospitality Management*, *35(10),* 3662-3680, p. 6.
7. Gasparski, P. (2016). Myślenie szybkie i wolne a optymizm dotyczący osobistych zasobów pieniężnych. *Studia Ekonomiczne, 1*, p. 135.
8. Groes, C., Nørmark, D. (2024). *Gid min chef var høvding: Sådan får vi de ledere, vi fortjener*. Gyldendal A/S., p. 55.
9. Güttel, W.H., Kleinhanns-Rollé, A. (2021). 2.1 Leadership Landscape: Führungsfähigkeiten, Führungsidentität und Führungseffektivität. In: *Erfolgreich in turbulenten Zeiten* (pp. 159-181). Rainer Hampp Verlag, p. 67.
10. Hensellek, S., Kleine-Stegemann, L., Kollmann, T. (2023). Entrepreneurial leadership, strategic flexibility, and venture performance: Does founders' span of control matter? *Journal of Business Research*, *157*, 113544, pp. 1-3.
11. Kahneman, D., Szymczak, P., Tversky, A. (2019). *Pułapki myślenia: o myśleniu szybkim i wolnym*. Poznań: Media Rodzina, p. 15.
12. Kraczla, M. (2013) .*Osobowościowe uwarunkowania przywództwa: menedżerowie a specjaliści*. Wyższa Szkoła Biznesu, pp. 32-86.
13. Kurdoglu, R.S., Lerner, D., Ates, N.Y. (2022). Unsticking the rationality stalemate: motivated reasoning, reality, and irrationality. *Journal of Business Venturing Insights*, *18*, e00336, pp. 4-8.
14. Mai, N., Do, T., Phan, N. (2022). The impact of leadership traits and organizational learning on business innovation. *Journal of Innovation & Knowledge*, *7(3),* 100204, pp. 1-3.

15. Mazumdar, D., Mukhopadhyay, G. (2012). Leadership Quotient, *Journal of Organization and Human Behavior*, *1,* pp. 17-20.
16. Reinisch, M. (2019). *Führungskompetenz im Spiegel von Ich und Du*. PhD Thesis. lmu., pp. 33-50.
17. Rożnowski, B., Fortuna, P. (2020). *Psychologia biznesu: psychologia w biznesie*. Warszawa: PWN, p. 321.
18. Saint-Michel, S.E. (2023). *VI/L'approche cognitive du leadership: bousculer la représentation du leader. Repères*, pp. 91-103.
19. Smith, T., Southern, R., Kirkpatrick, K. (2023). Mechanisms of impulsive choice: Experiments to explore and models to map the empirical terrain. *Learning & Behavior*, *1-37,* pp. 2-4.
20. Strang, M., Miller, M., Hill, R., Elshaw, J. (2023). Group decision performance: The predictive role of decision making styles and cognition. *Personality and Individual Differences, 206,* 112114, p. 10.
21. Swoboda, B., Schramm-Klein, H. (2025). *Käuferverhalten: Customer Insights–Customer Journey–Customer Relations*. Springer-Verlag, p. 46.
22. Szydłowski, P. (2015). Pomiar stylu analitycznego przetwarzania informacji. Wstępna weryfikacja narzędzi: testu Cognitive Reflection Test (CRT) i zadań Base-Rate Tasks (BRT). *Studia Psychologica: Theoria et praxis*. *15.2,* pp. 60-75.
23. Trost, A. (2022). Führung im Hier und Jetzt. In: *Das richtige Führungsverständnis* (p. 134). Berlin/Heidelberg: Springer Gabler.
24. Van Dick, R., Fink, L. (2019). *Führungsstile: Prominenten und Persönlichkeiten über die Schulter geschaut*. Berlin/Heidelberg: Springer, pp. 7-11.
25. Zada, M., Khan, J., Saeed, I., Zada, S., Jun, Z.Y. (2023). *Linking public leadership with project management effectiveness: Mediating role of goal clarity and moderating role of top management support*. Heliyon, p. 11.
26. Zhang, X. (2023). The influence of user cognition on consumption decision-making from the perspective of bounded rationality. *Displays, 77,* 102392, p. 3.
27. Zulaikha, N. (2022). The influence of leadership skills on organizational management: a conceptual review. *International Journal of Behavioral Analytics*, *2(4),* pp. 1-7.

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ORGANIZATION AND MANAGEMENT SERIES NO. 224

NEURODIVERSITY IN THE SERVICE OF HUMANISM OF ENTREPRENEURIAL MANAGEMENT

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Purpose: The objective is to outline the role of the entrepreneurial state of mind in relation to opportunities (central for entrepreneurial management), as unquestionably human and irreplaceable by the products of technology.
Design/methodology/approach: The study is theoretical and argumentative in nature, constituting the author's own reflection and voice in the discussion, strengthening the belief in entrepreneurial management as immanently embedded in human nature. The study uses the method of literature review.
Findings: In the conditions of the critical role of the human in entrepreneurial management and the simultaneous opening of contemporary socio-economic realities to the human, with their specific, individualized perception of reality, it can be said that there is a significant potential to resist replacement by technology. The role of the human mind reinforces their role in today's economic realities. Regardless of the development of technology, the role of humans in entrepreneurship seems to be crucial and the existence of differences or even deficiencies at the neurological and psychological level, leading to unique states of mind, reinforces the role of the individual irrespective of the directions of development of economic practice. The diversification of perceptions of business environment, provided by neurodiversity, appears to be a significant contribution to entrepreneurial potential. Neurodiversity is an important factor in entrepreneurial management, and its existence generates the prerequisite for its highly humanistic character. Its outcome, manifested in the exploitation of opportunities, is marked by the results of the unique functioning of the entrepreneur's human brain and thus their state of mind.
Originality/value: In the paper it is proposed to draw attention to the impact of the specific role of neurodiversity and the resulting entrepreneurial states of mind on maintaining the key role of the human and humanity in entrepreneurial management. Many papers contain the results of research and analysis on the impact of neurological and psychological dysfunctions on the entrepreneurial process. However, they do not pay attention to the special fact that precisely these different states of mind determine the humanistic nature of entrepreneurship.
Keywords: entrepreneurial management (EM), opportunity, entrepreneurship, ADHD, emotions, mindset, neurodiversity.
Category of the paper: Viewpoint, Conceptual paper.

1. Introduction

One of the sources of the company's competitive advantage is entrepreneurial management. It is aimed at a constant search for opportunities and their effective use. It involves a deliberate and organized analysis of opportunities for economic or social innovation (Pierścionek, 2007). Understanding why, when and how opportunities arise is a fundamental area of exploration in entrepreneurship (Shane, Venkataraman, 2000). Individual-opportunity (IO) nexus is the dominant approach in research into entrepreneurship, even referred to as a paradigm (Klangboonkrong, Baines, 2022).

In terms of entrepreneurial opportunities, the human plays a key role, since it is at their level that opportunities are identified, and decisions concerning their further fate made. This is crucial in the face of a universal threat to dehumanizing the operation of enterprises due to the growing role of artificial intelligence (AI) and attempts to replace human work with machines. According to Haynie et al. (2009), whether an entrepreneurial opportunity is perceived as attractive depends precisely on the individual perspective and the entrepreneur's position. While evaluating opportunities and making decisions about whether to pursue them, entrepreneurs make judgments in the conditions of uncertainty and complexity (Keh et al., 2002). Their state of mind, which is the factor that determines qualifying for or rejecting an opportunity, plays a significant role in these challenging circumstances.

Not everyone has the same ability to recognize and seize an entrepreneurial opportunity. Individual characteristics make some persons better equipped than others. These include previous experience, social network, cognitive abilities, economic conditions, and psychological factors. The population is heterogeneous, which explains why some people become entrepreneurs (Alvarez, Busenitz, 2001; Kuechle, 2011). This heterogeneity also suggests diversity at the neurological level of a human, which leads to various mindsets of entrepreneurs and thus different behavior in terms of business management. The concept of neurodiversity emerges in these circumstances - based on the belief that natural variations in the human genome lead to differences in the way of thinking (Lanivich et al., 2024).

In the light of the above, the thesis of this paper is that the heterogeneity of entrepreneurial state of mind plays a key role in reinforcing the humanistic nature of entrepreneurial management as a process inherent in human nature and resistant to replacement by machines and AI. The research problem is formulated in the form of the following research question: How does the heterogeneity of entrepreneurial state of mind affect reinforcing the humanistic nature of entrepreneurial management, based on discovering and exploiting opportunities? While staying in line with the considerations on the analysis of IO nexus, the objective of this study is to identify and indicate the role of the entrepreneurial state of mind in relation to opportunities, as outstanding, unquestionably human and irreplaceable by the products of modern technology.

The study is theoretical and argumentative in nature, constituting the author's own reflection and voice in the discussion, strengthening the belief in entrepreneurial management as immanently embedded in human nature and irreplaceable by machines. The study uses the method of literature review, the role of which in contemporary science is growing (Snyder, 2019; Najda-Janoszka, 2023), enabling the synthesis of knowledge (Breslin, Gatrell, 2020), problematizing and reinterpreting achievements through new observations or theoretical approaches (Fan et al., 2022; Snyder, 2019).

2. Various states of mind and IO nexus

The entrepreneur, while discovering and exploiting opportunities, engages their own personality traits, cognitive skills (psychological factors) and a set of skills that are non-psychological factors (affecting access to information) (Fuduric, 2008). The cognitive processes of entrepreneurs are different and influence the identification of entrepreneurial opportunities. The existence of specific mental patterns that facilitate their identification is emphasized (Franka, Mitterer, 2009). Opportunities are a subjective phenomenon, since they depend on the degree of ambiguity of the environment and the ability of social actors to create mental models, implying thinking patterns necessary to interpret, and ultimately, to define those opportunities as actually opportunities (Companys, McMullen, 2007). Through mental processes, a human creates an individual, subjective vision of the situation in which they currently operate, which can vary depending on the individual state of mind.

The identification of opportunities is related to cognitive processes, reducing, transforming and using sensory stimuli from the environment, so that the behavior results from complex interactions between cognition, environment and mind (Neisser, 1967). Entrepreneurial cognition, dependent on the state of mind, is defined as the structures of knowledge used by people to make assessments, judgments or decisions related to evaluating opportunities, creating projects and developing them (Christensen, 2024). In addition to cognitive factors, entrepreneurial alertness is particularly important to identify opportunities, as it is an outline which allows organizing and interpreting information in various areas of knowledge related to developing new opportunities (Gaglio, Katz, 2001; Kirzner, 1999). Kirzner (1973) defined alertness, referring directly to opportunities, as the ability which helps some individuals notice potential economic benefits resulting from changes, shifts, gaps and new opportunities in the market.

There is a growing number of research efforts under neuroscience aimed at understanding how neurobiological differences (brain-related) relate to entrepreneurial factors (Phan, Wright, 2018; Sharma et al., 2021). Austin and Pisano (2017) argue that neuro-different people have a different 'connection structure' from 'neurotypical' people, which means that they can bring

new perspectives to the company's activities related to value creation or recognition, which may include the perception of opportunities. While there are many ways to understand neurodiversity and neurological functioning, Rosqvist et al. (2020) suggested that its key element is a "broader continuum of sensory, affective and cognitive processing". As pinpointed by Irish (2025), research into neurodiversity in a narrow sense focuses primarily on specific, neurodiverse ways of being, but there is also a more general approach. In this view, the concept of neurodiversity reflects the fact that there is natural variability in cognitive, emotional, and sensory functioning in the human population, and neurological styles occur with varying frequency. These differences in neurological functioning lead to a wide range of internal subjective experiences and external behavior that shape the way a human interacts with the world. Human minds and bodies are infinitely different in the way they work (Irish, 2025). Thus, each person in a way is differently capable, for all are born and reared differently. Thinking patterns are the result of both innate "mechanism" and "experiences" that have "programmed" people (Austin, Pisano, 2017).

3. Neurodiversity in entrepreneurial activities – against schematic thinking

Scientific interest in the functionality of mental health disorders in entrepreneurship is growing (Leung et al., 2020; Hatak et al., 2021). People who experience mental disorders are, by definition, atypical. To a certain extent, entrepreneurs are essentially non-stereotypical entities, which indicates the validity of studies aimed at identifying areas common to both mentioned groups. As an example, it can be indicated that energy levels, extroversion, risk-taking and optimism of individuals with a bipolar disorder in a hypomanic state are consistent with variables that have received considerable attention in the literature on entrepreneurship (Frese, Gielnik, 2014). Particular attention should also be paid to the line in entrepreneurship research focused on the impact of mental health and related disorders, such as attention deficit hyperactivity disorder (ADHD), on entrepreneurial processes and performance (Antshel, 2018; Lerner et al., 2018; Stephan, 2018; Wiklund et al., 2018). Wiklund et al. (2024), claim that the concept of neurodiversity considers neurological differences, such as autism, ADHD, and dyslexia, as natural variants of human cognition, not deficits. This approach, they argue, is important for the field of entrepreneurship since it highlights the unique skills and perspectives that neurodiverse entrepreneurs can bring.

Based on neurocognitive perspectives, ADHD is seen as a result of biological differences in specific brain areas causing deficits in higher-order cognitive control and reward functions that are critical to goal-oriented decision-making (i.e., executive functions of the brain). Executive functions enable adaptive, goal-oriented thinking and behavior in new or changing situations (Roebers, 2017) - similar to those experienced by entrepreneurs operating in the

conditions of lack of information and uncertainty, making decisions related to seizing opportunities (Mitchell et al., 2007). ADHD additionally extends the span of attention of individuals (Kasof, 1997), which may help to identify new opportunities (Shepherd et al., 2007). ADHD symptoms, related to negative consequences in many areas of life, have positive implications in the context of entrepreneurship. ADHD is characterized, among others, by thrill seeking, focusing on activities with little thought, and a desire for autonomy. Entrepreneurship, therefore, is a particular area where ADHD-related traits are an asset (Wiklund et al., 2017).

It is argued that intuition, commonly used in decision-making by individuals with ADHD and dyslexia (Logan, 2009), is important for the effective development of large packages of opportunities which are too large to be subjected to systematic analysis in a timely manner. Kickul et al. (2009) claim that people with intuitive cognitive styles are more likely to scan and search for information and more confident in identifying and recognizing opportunities. At the same time, the characteristics associated with the symptoms of mental disorders contribute to generating large sets of opportunities. Therefore, one of the benefits generated by the symptoms of mental disorders (e.g. increased number of recognized opportunities) is amplified by another symptom of the same or another disorder (e.g. intuitive decision-making) to increase the effectiveness of entrepreneurial activity related to opportunities (Logan, 2009). In the case of bipolar disorders and ADHD (Kasof, 1997), which are linked to higher levels of creativity, people generate more innovative opportunities. These people often develop original ways of analyzing and redefining situations, enabling them to identify opportunities that others cannot even imagine. (Logan, Martin, 2012).

Entrepreneurs with ADHD exhibit a significantly higher level of entrepreneurial alertness - a mental pattern conducive to the identification of opportunities (Gaglio, Katz, 2001; Tang et al., 2012) than those without ADHD. Entrepreneurs with ADHD are constantly looking for new opportunities, since they are biologically predisposed or even programmed to do so. However, this tendency can also make it difficult for them to focus on one opportunity long enough to make it seized (Moore, 2021).

Entrepreneurial performance depends on openness to new situations and curiosity (Zhao et al., 2010), which seems to be consistent with the sensation seeking which is typical of ADHD symptoms. People with high levels of sensation seeking are naturally curious (Jackson, 2011) and take a more positive approach to new situations (Nicolaou et al., 2008), especially when the environment is highly exploratory and contains new stimuli, as is the case of entrepreneurship (Wiklund et al., 2017). This stimulation is essential in identifying and exploiting opportunities.

All states of mind, including those resulting from a state of neurodiversity, are accompanied by emotions that are about the uniqueness of an individual and their 'non-technical' nature. Entrepreneurs' cognitive processes, motivation and all actions are influenced by discrete emotions (e.g. Welpe et al., 2012) and dispositional affect (e.g. Baron et al., 2012). Emotions influence both the evaluation of opportunities and decisions regarding their exploitation

(Hayton et al., 2012; Welpe et al., 2012). Under the process of preceding opportunity exploitation, emotions affect the impact of the cognitive evaluation of an opportunity on the tendency to exploit it.

4. The unquestionable role of a human in entrepreneurial management

The literature emphasizes that those aspects of business activity that require social and creative skills, particularly those related to decision-making in situations of uncertainty and the development of innovative ideas are less at risk to automation, and thus dehumanization (Skrzypek, 2020), and these can be discovering or even creating entrepreneurial opportunities and taking a decision to exploit them.

The significant role of the human mind in entrepreneurial management allows for the conclusion that this role is inscribed in the ideas of Industry 5.0, which introduces the anthropocentric approach, in which technologies support human creativity and capabilities (Breque et al., 2021) rather than replace them. This is also confirmed by the findings by Bielawski (2024), that the overriding skills in the Industry 5.0 era include, among others, an entrepreneurial mindset, which is crucial for the competitiveness of enterprises. It is claimed that even the most advanced technology should not be above humanity (Sułkowski et al., 2021; Carayannis, Morawska-Jancelewicz, 2022; Ingaldi, Ulewicz, 2020). In conclusion, it can be stated with confidence that, thanks to entrepreneurial mind, the entrepreneur's role is not threatened, and so the role of entrepreneurs, inscribed in the Society 5.0 concept, crucial in shaping the future social landscape (Ćoćkalo et al., 2024) will be preserved.

In the above circumstances, which constitute contemporary socio-economic realities, the role of entrepreneurship appears to be fundamental, and the role of a human in entrepreneurial management is immanent and crucial. It is human characteristics that determine the way in which the entrepreneurial process is carried out, and entrepreneurial management, based on the discovery and exploitation of opportunities, is rooted in human nature, which, due to its diversity arising from biological conditions, constitutes an inexhaustible and unlimited resource supporting entrepreneurship, understood both at organizational and individual levels.

In the conditions of the critical role of the human in entrepreneurial management and the simultaneous opening of contemporary socio-economic realities to the human, with their unique nature, strengths and weaknesses and specific, individualized perception of reality, it can be said that there is a significant potential to resist replacement by technology. The role of the human mind reinforces their role in today's economic realities. Regardless of the development of technology and the replacement of selected aspects of reasoning by artificial intelligence, the role of humans in entrepreneurship seems to be crucial and the existence of differences or

even deficiencies at the neurological and psychological level, leading to unique states of mind, reinforces the role of the individual irrespective of the directions of development of economic practice.

5. Conclusions

Today's business world needs entrepreneurs who proactively create economic reality by looking at and analyzing the world from a broader perspective, which will contribute to a more creative and development-oriented discovery and exploitation of opportunities. Any diversified openness to new ideas, willingness to accept non-standard ideas and approaches, and unleashing the entrepreneurial spirit are key features for getting entrepreneurship moving.

Just as Taylorism no longer refers to the contemporary conditions in which enterprises operate, the diversification of perceptions of the environment, provided by neurodiversity, appears to be a significant contribution to the empowerment of entrepreneurial potential and thus the creation of new business ventures based on the exploitation of unique opportunities.

Machines do not have human senses, emotions or social skills (Kaplan, Haenlein, 2019; Raisch, Krakowski, 2021). Entrepreneurship, on the other hand, involves specific social tasks (Seyb et al., 2019) and can provide the human element, emotions and high-quality relationships that support AI (Shepherd, Majchrzak, 2022) but technological advances in computation cannot replace the competitive discovery process that takes place within the context of the market (Boettke et al., 2023). Referring to opportunities requires an appropriate level of mental commitment, human creativity and intuition, and machines do not have enough intelligence to propose solutions that are beyond the reach of the entrepreneurial mind (Ge et al., 2022). Thus, in defense of the thesis set out in the introduction to the present study, it is possible to quote Van Den Hauwe, L. (2023), that machines will not replace entrepreneurs whereas neurodiversity in particular is about the humanistic nature of entrepreneurial management.

In the light of the above considerations, it should be confirmed that broadly understood neurodiversity is an important factor in entrepreneurial management, and its existence generates the prerequisite for its highly humanistic character. Its outcome, manifested in the exploitation of opportunities, is marked by the results of the unique functioning of the entrepreneur's human brain and thus their state of mind.

The article is theoretical in its nature, therefore, the major limitation of the conducted study, based on the analysis of literature, is the lack of empirical results. Among the directions for further research one may indicate testing neurodiversity-performance relationship or designing inclusive entrepreneurship programs.

References

1. Alvarez, S.A., Busenitz, L.W. (2001). The entrepreneurship of resource-based theory. *Journal of Management, 27(6),* pp. 755-775, https://doi.org/10.1177/014920630102700609
2. Antshel, K.M. (2018). Attention deficit/hyperactivity disorder (ADHD) and entrepreneurship. *Academy of Management Perspectives, 32(2),* pp. 243-265, https://doi.org/10.5465/amp.2016.0144
3. Austin, R.D., Pisano, G.P. (2017). Neurodiversity as a competitive advantage. *Harvard Business Review, 95(3),* pp. 96-103.
4. Baron, R.A., Hmieleski K.M., Henry R.A. (2012). Entrepreneurs' dispositional positive affect: The potential benefits—and potential costs—of being "up". *Journal of Business Venturing, 27(3),* pp. 310-324, https://doi.org/10.1016/j.jbusvent.2011.04.002
5. Bielawski, R. (2024). Marketing w Przemyśle 5.0: integracja człowieka z technologią. In: M. Kuroń, M. Piłat-Borcuch, N. Stępnicka (eds.), *Współczesne wyzwania w społeczeństwie, technologii i medycynie* (pp. 9-22). Łódź: ArchaeGraph.
6. Boettke, P.J., Candela, R.A. (2023). On the feasibility of technosocialism. *Journal of Economic Behavior & Organization, Vol. 205*, pp. 44-54, https://doi.org/10.1016/j.jebo.2022.10.046
7. Breslin, D., Gatrell, C. (2020). Theorizing Through Literature Reviews: The Miner-Prospector Continuum. *Organizational Research Methods, 26(1)*, pp. 139-167, https://doi.org/10.1177/1094428120943288
8. Carayannis, E.G., Morawska-Jancelewicz, J. (2022). The Futures of Europe: Society 5.0 and Industry 5.0 as Driving Forces of Future Universities. *Journal of the Knowledge Economy, 13(4)*, pp. 3445-3471, https://doi.org/10.1007/s13132-021-00854-2
9. Christensen, B.T. (2024). Creative cognition and entrepreneurship. In: L.J. Ball, F. Vallée-Tourangeau (eds.), *The Routledge International Handbook of Creative Cognition* (pp. 698-708). Routledge.
10. Ćoćkalo, D., Bakator, M., Stanisavljev, S., Nikolić, M., Stojanović, E.T., Kavalić, M., Kovač, D. (2024). *The future of work and innovation: Entrepreneurship at the crossroads of Society 5.0 and Industry 5.0*, 21-26. Engineering Management and Compeitiveness (EMC 2024).
11. Companys Y.E., McMullen, J.S. (2007). Strategic Entrepreneurs at Work: The Nature, Discovery, and Exploitation of Entrepreneurial Opportunities. *Small Business Economics, 28*, pp. 301-322, https://doi.org/10.1007/s11187-006-9034-x
12. European Commission: Directorate-General for Research and Innovation, Breque, M., De Nul, L., Petridis, A. (2021). *Industry 5.0 – Towards a sustainable, human-centric and resilient European industry.* Publications Office of the European Union.

13. Fan, D., Breslin, D., Callahan, J.L., Iszatt-White, M. (2022). Advancing literature review methodology through rigour, generativity, scope and transparency. *International Journal of Management Reviews, 24(2)*, pp. 171-180, https://doi.org/10.1111/ijmr.12291
14. Frank, H., Mitterer, G. (2009). Opportunity Recognition – State of the Art und Forschungsperspektiven. *Zeitschrift fur Betriebswirtschaft, 79(3)*, pp. 367-406, https://doi.org/10.1007/s11573-008-0223-8
15. Frese, M., Gielnik, M.M. (2014). The psychology of entrepreneurship. *Annual Review of Organizational Psychology and Organizational Behavior, 1(1)*, pp. 413-438, https://doi.org/10.1146/annurev-orgpsych-031413-091326
16. Fuduric, N. (2008). *Individuals & Opportunities: A resource-based and institutional view of entrepreneurship.* PhD Thesis. Aalborg: Aalborg University.
17. Gaglio, C.M., Katz, J.A. (2001). The psychological basis of opportunity identification: Entrepreneurial alertness. *Small Business Economics, 16(2),* pp. 95-111, https://doi.org/10.1023/A:1011132102464
18. Ge, B., Wang, Q., Yao, M. (2022). From ideas to entrepreneurial opportunity: A study on AI Systems. *Research and Behavioral Science, 39(3),* pp. 618-632, https://doi.org/10.1002/sres.2874
19. Hatak, I., Chang, M., Harms, R., Wiklund, J. (2021). ADHD symptoms, entrepreneurial passion, and entrepreneurial performance. *Small Business Economics, 57*, pp. 1693-1713, https://doi.org/10.1007/s11187-020-00397-x
20. Hauwe, L., Van Den (2023). Why machines will not replace entrepreneurs. On the inevitable limitations of artificial intelligence in economic life. *Procesos de Mercado: Revista Europea de Economía Política, Vol. XX, no. 2.* Otoño, pp. 227-264.
21. Haynie, J.M., Shepher, D.A., McMullen, J.S. (2009). An opportunity for me? The role of resources in opportunity evaluation decisions. *Journal of Management Studies, 46(3)*, pp. 337-361, https://doi.org/10.1111/j.1467-6486.2009.00824.x
22. Hayton, J.C., Cholakova, M. (2012). The role of affect in the creation and intentional pursuit of entrepreneurial ideas*, Entrepreneurship Theory and Practice, 36(1)*, pp. 41-68.
23. Ingaldi, M., Ulewicz, R. (2020). Problems with the Implementation of Industry 4.0 in Enterprises from the SME Sector. *Sustainability, 12(1)*, p. 217. https://doi.org/10.3390/su12010217
24. Irish, B.J. (2025). Historical Neurodiversity Studies: A New Paradigm of Experience. *History and Theory*, pp. 1-13.
25. Jackson, C.J. (2011). How sensation seeking provides a common basis for functional and dysfunctional outcomes. *Journal of Research in Personality, 45(1),* pp. 29-36, https://doi.org/10.1016/j.jrp.2010.11.005
26. Kaplan, A., Haenlein, M. (2019). Siri, Siri, in my hand: Who's the fairest in the land? On the interpretations, illustrations, and implications of artificial intelligence. *Business Horizons, 62(1)*, pp. 15-25, https://doi.org/10.1016/j.bushor.2018.08.004

27. Kasof, J. (1997). Creativity and breadth of attention. *Creativity Research Journal, 10(4)*, pp. 303-315, https://doi.org/10.1207/s15326934crj1004_2
28. Keh, H.T., Foo, M.D., Lim, B.C. (2002). Opportunity evaluation under risky conditions: The cognitive processes of entrepreneur. *Entrepreneurship theory and practice, 27(2),* pp. 125-148, https://doi.org/10.1111/1540-8520.00003
29. Kickul, J., Gundry, L.K., Barbosa, S.D., Whitcanack, L. (2009). Intuition versus analysis? testing differential models of cognitive style on Entrepreneurial self-efficacy and the new venture creation process. *Entrepreneurship Theory and Practice, 33(2)*, pp. 439-453, https://doi.org/10.1111/j.1540-6520.2009.00298.x
30. Kirzner, I.M. (1973). *Competition and entrepreneurship*. University of Chicago Press.
31. Kirzner, I.M. (1999). Creativity and/or alertness: A reconsideration of the Schumpeterian entrepreneur. *The Review of Austrian Economics, 11(1/2)*, pp. 5-17.
32. Klangboonkrong, T., Baines, N. (2022). Disability entrepreneurship research: Critical reflection through the lens of individual-opportunity nexus. *Strategic Change, 31(4)*, pp. 427-445, https://doi.org/10.1002/jsc.2513
33. Kuechle, G. (2011). Persistence and heterogeneity in entrepreneurship: An evolutionary game theoretic analysis. *Journal of Business Venturing, 26(4)*, pp. 458-471, https://doi.org/10.1016/j.jbusvent.2009.12.001
34. Lanivich, S.E., Moore, C., McIntyre, N. (2024). The effects of neurodiversity on cognitive attributes of entrepreneurs. *International Journal of Entrepreneurial Behavior & Research, 30(4)*, pp. 979-1000, https://doi.org/10.1108/IJEBR-12-2022-1079
35. Lerner, D.A., Hunt, R.A., Verheul, I. (2018). Dueling Banjos: Harmony and discord between ADHD and entrepreneurship. *Academy of Management Perspectives, 32(2)*, pp. 266-286, https://doi.org/10.5465/amp.2016.0178
36. Leung, Y.K., Franken, I.H.A., Thurik, A.R. (2020). Psychiatric symptoms and entrepreneurial intention: The role of the behavioral activation system. *Journal of Business Venturing Insights, 13*, p. e00153, https://doi.org/10.1016/j.jbvi.2019.e00153
37. Logan, J. (2009). Dyslexic entrepreneurs: The incidence; their coping strategies and their business skills. *Dyslexia, 15(4),* pp. 328-346, DOI: 10.1002/dys.388
38. Logan, J., Martin, N. (2012). Unusual talent: A study of successful leadership and delegation in entrepreneurs who have dyslexia. *Inclusive Practice, 4*, pp. 57-76.
39. Mitchell, R.K., Busenitz, L.W., Bird, B., Marie Gaglio, C., McMullen, J.S., Morse, E.A., Smith, J.B. (2007). The central question in Entrepreneurial cognition research 2007. *Entrepreneurship Theory and Practice, 31(1),* pp. 1-27, https://doi.org/10.1111/j.1540-6520.2007.00161.x
40. Moore, C.B., McIntyre, N.H., Lanivich, S.E. (2021). ADHD-related neurodiversity and the entrepreneurial mindset. *Entrepreneurship Theory and Practice, 45(1)*, pp. 64-91, https://doi.org/10.1177/1042258719890986

41. Najda-Janoszka, M. (2023). Przegląd literatury w perspektywie mieszanej. In: L. Sułkowski, R. Lenart-Gansiniec (eds.), *Metody badań mieszanych w naukach o zarządzaniu* (pp. 39-58). Dąbrowa Górnicza: Wydawnictwo Naukowe Akademii WSB.
42. Neisser, U. (1967). *Cognitive psychology*. Prentice-Hall.
43. Nicolaou, N., Shane, S., Cherkas, L., Spector, T.D. (2008). The influence of sensation seeking in the heritability of entrepreneurship. *Strategic Entrepreneurship Journal, 2(1)*, pp. 7-21, https://doi.org/10.1002/sej.37
44. Phan, P., Wright, M. (2018). Advancing the science of human cognition and behavior. *Academy of Management Perspectives, 32(3)*, pp. 287-289, https://doi.org/10.5465/amp.2018.0058
45. Pierścionek, Z. (2007). *Strategie konkurencji i rozwoju przedsiębiorstwa*. Warszawa: PWN.
46. Raisch, S., Krakowski, S. (2021). AI and management: The automation–augmentation paradox. *Academy of Management Review, 46(1)*, pp. 192-210, https://doi.org/10.5465/amr.2018.0072
47. Roebers, C.M. (2017). Executive function and metacognition: Towards a unifying framework of cognitive self-regulation. *Developmental Review, 45*, pp. 31-51, https://doi.org/10.1016/j.dr.2017.04.001
48. Rosqvist, H.B., Stenning, A., Chown, N. (2020). *Neurodiversity Studies*. Cambridge University Press, pp. 1-11.
49. Seyb, S.K., Shepherd, D.A., Williams, T.A. (2019). Exoskeletons, entrepreneurs, and communities: A model of co-constructing a potential opportunity. *Journal of Business Venturing, 34(6)*, p. 05947, DOI: 10.1016/j.jbusvent.2019.105947
50. Shane, S., Venkataraman, S. (2000). The promise of entrepreneurship as a field of research, *Academy of Management Review, 25(1)*, pp. 217-226, https://doi.org/10.5465/amr.2000.2791611
51. Sharma, G.D., Paul, J., Srivastava, M., Yadav, A., Mendy, J., Sarker, T., Bansal, S. (2021). Neuroentrepreneurship: an integrative review and research agenda. *Entrepreneurship & Regional Development, 33(9-10)*, pp. 863-893, https://doi.org/10.1080/08985626.2021.1966106
52. Shepherd, D.A., Majchrzak, A. (2022). Machines augmenting entrepreneurs: Opportunities (and threats) at the Nexus of artificial intelligence and entrepreneurship. *Journal of Business Venturing, 37(4)*, pp. 106-227, https://doi.org/10.1016/j.jbusvent.2022.106227
53. Shepherd, D.A., McMullen, J.S., Jennings, P.D. (2007). The formation of opportunity beliefs: Overcoming ignorance and reducing doubt. *Strategic Entrepreneurship Journal, 1(1-2)*, pp. 75-95, https://doi.org/10.1002/sej.3
54. Skrzypek, E. (2020). Czwarta rewolucja przemysłowa – szansa czy zagrożenie dla człowieka i świata. In: E. Bojar (ed.), *Przyszłość zarządzania. Wyzwania w dobie postglobalizacji* (pp. 423-426). Toruń: Towarzystwo Naukowe Organizacji i Kierownictwa „Dom Organizatora".

55. Snyder, H., (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research, 104,* pp. 333-339, https://doi.org/10.1016/j.jbusres.2019.07.039
56. Stephan, U. (2018). Entrepreneurs' mental health and well-being: A review and research agenda. *Academy of Management Perspectives, 32(3),* pp. 290-322, https://doi.org/10.5465/amp.2017.0001
57. Sułkowski, Ł., Kolasinska-Morawska, K., Seliga, R., Morawski, P. (2021). Smart learning technologization in the Economy 5.0-The Polish perspective. *Applied Science, 11*, pp. 52-61, https://doi.org/10.3390/app11115261
58. Tang, J., Kacmar, K., Busenitz, L. (2012). Entrepreneurial alertness in the pursuit of new opportunities. *Journal of Business Venturing, 27(1)*, pp. 77-94, https://doi.org/10.1016/j.jbusvent.2010.07.001
59. Welpe, I.M., Spörrle, M., Grichnik, D., Michl, T., Audretsch, D.B. (2012). Emotions and opportunities: The interplay of opportunity evaluation, fear, joy, and anger as antecedent of entrepreneurial exploitation. *Entrepreneurship Theory and Practice, 36(1)*, pp. 69-96, https://doi.org/10.1111/j.1540-6520.2011.00481.x
60. Wiklund, J., Hatak, I., Patzelt, H., Shepherd, D.A. (2018). Mental disorders in the entrepreneurship context: When being different can be an advantage. *Academy of Management Perspectives, 32(2)*, pp. 182-206, https://doi.org/10.5465/amp.2017.0063
61. Wiklund, J., Tran, M.H., Rahm, R. (2024). Neurodiversity and Entrepreneurship. In: E. Patton, A.M. Santuzzi (eds.), *Neurodiversity and Work: Employment, Identity, and Support Networks for Neurominorities* (pp. 283-309). Cham: Springer Nature Switzerland.
62. Wiklund, J., Yu, W., Tucker, R., Marino, L. (2017). ADHD, impulsivity, and entrepreneurship. *Journal of Business Venturing, 32(6)*, pp. 627-656, https://doi.org/10.1016/j.jbusvent.2017.07.002
63. Zhao, H., Seibert, S.E., Lumpkin, G.T. (2010). The relationship of personality to entrepreneurial intentions and performance: a meta-analytic review. *Journal of Management, 36(2)*, pp. 381-404, https://doi.org/10.1177/0149206309335187

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LEADERSHIP AND EMPOWERMENT: EXAMINING THE RELATIONSHIP BETWEEN TRANSFORMATIONAL LEADERSHIP AND EMPLOYEE EMPOWERMENT IN PROJECT MANAGEMENT

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Purpose: The research aim was to investigate the relationship between transformational leadership and employee empowerment within the context of project management in Polish public administration. It examines whether transformational leadership is the predominant style in this environment and whether it enhances employee empowerment during project implementation.
Design/methodology/approach: The survey selected 18 offices in Poland's voivodeship capitals and included all 269 departments and faculties. Directors nominated employees for a questionnaire focusing on projects needing diverse skills. Seventy employees (and projects) were selected, with 50 responding to the subsequent survey via computer-assisted telephone interviewing (CATI). The study utilized validated leadership and empowerment scales with a -2 to 2 rating system. Data analysis included exploratory factor analysis using principal component analysis, descriptive statistics, and correlation analysis to examine relationships between variables.
Findings: The results reveal that transformational leadership is not the predominant public administration project management style. Moreover, managers do not actively empower their employees during project implementation. Contrary to expectations, no significant correlation was found between transformational leadership and employee empowerment ($r = 0.185$, $p > 0.01$).
Research limitations/implications: Limitations include potential self-selection bias among participants and unaccounted external variables such as political pressures or funding constraints that might influence leadership-empowerment dynamics. Future research should include comparative studies using similar methodology in the private sector in Poland and other countries' public sectors.
Practical implications: The research results indicate the need to strengthen empowerment efforts to foster better teamwork. They also indicate investing in leadership development

programs that promote leadership qualities such as inspiring and motivating employees, supporting empowerment, and aligning goals with the organisation's mission.
Social implications: Encouraging leadership qualities like empowerment and transparency contributes to a more accountable and socially responsible public sector. Enhancing leadership practices in public administration can lead to more responsive and efficient public services, ultimately benefiting citizens through improved project outcomes.
Originality/value: The study provides novel insights into the specific context of Polish public administration, challenging conventional assumptions about transformational leadership's universal effectiveness in enhancing employee empowerment. It offers valuable guidance for leadership development in public institutions.
Keywords: transformational leadership, public administration, project management, employee empowerment.
Category of the paper: Research paper.

1. Introduction

In recent decades, the evolution of leadership paradigms has significantly influenced organizational dynamics and performance outcomes. Among these paradigms, transformational leadership has emerged as a prominent model that emphasizes inspiration, intellectual stimulation, and individual consideration (Bass, 2006). Concurrently, employee empowerment has gained recognition as a critical factor in enhancing organizational effectiveness and innovation (Spreitzer, 2008). The intersection of these two concepts—transformational leadership and employee empowerment—presents a compelling area of research, particularly within the context of project management in public administration.

The originality of this study lies in its focus on the understudied context of Polish public administration project management, where the relationship between transformational leadership and employee empowerment has not been systematically investigated. While extensive research exists on these concepts in private sector organizations and Western public administrations, this study provides the first empirical examination of their interaction within the unique institutional environment of Central European public administration, specifically addressing the gap in understanding how post-communist administrative reforms have influenced contemporary leadership practices and empowerment dynamics in project-based work.

Public administration organizations often operate under unique constraints, including bureaucratic structures, political influences, and strict regulatory frameworks (Denhardt, Denhardt, 2015). These constraints can potentially impact leadership styles and empowerment practices, creating a distinct environment that warrants specialized research. Despite the extensive literature on leadership and empowerment in private sector organizations, there remains a notable gap in understanding how these concepts interact within public administration, especially in project management contexts (Van Wart, 2013).

Project management in public administration presents unique challenges that differentiate it from routine administrative functions. Projects typically involve temporary endeavors with specific objectives, timeframes, and resource allocations (Project Management Institute, 2017). The temporary and often cross-functional nature of project teams requires leadership approaches that can effectively mobilize diverse team members toward common goals while navigating the complexities of public sector constraints (Crawford, Helm, 2009).

The relationship between transformational leadership and employee empowerment has been theoretically established in general organizational contexts (Avolio et al., 2004). Transformational leaders are expected to enhance employee empowerment through inspirational motivation, intellectual stimulation, and individualized consideration (Bass, Avolio, 1994). However, the applicability of this relationship within public administration project management remains underexplored, particularly in the context of Eastern European countries like Poland, which have undergone significant public administration reforms in recent decades (Nemec, 2018).

This study aims to address this research gap by investigating the relationship between transformational leadership and employee empowerment within the specific context of project management in Polish public administration. By examining whether transformational leadership is the predominant style in this environment and whether it enhances employee empowerment during project implementation, the research contributes to both theoretical understanding and practical applications in public sector management. The study formulates one hypothesis and three research questions to guide the investigation. The hypothesis posits that the adoption of a transformational leadership style has a positive impact on employee empowerment. The research questions investigate whether transformational leadership is adopted as the predominant leadership style in project management, whether managers empower their employees in project management within public administration, and whether there is a significant correlation between the transformational leadership style and employee empowerment in project management. Through quantitative research methods, including factor analysis and correlation analysis, this study provides empirical evidence regarding the relationship between transformational leadership and employee empowerment in Polish public administration. The findings offer valuable insights for leadership development in public institutions and contribute to the broader discourse on effective leadership practices in public sector project management.

2. State of the art

The study of leadership and empowerment in organizational contexts has evolved significantly over the past several decades, with numerous theoretical frameworks and empirical studies contributing to our understanding of these concepts. This section provides a comprehensive review of the existing literature on transformational leadership, employee empowerment, and their interrelationship, with particular emphasis on project management in public administration.

Transformational leadership emerged as a distinct leadership theory through the seminal work of Burns (1978) and was further developed by Bass (1985). This leadership approach is characterized by four key dimensions: idealized influence (charisma), inspirational motivation, intellectual stimulation, and individualized consideration (Bass, Avolio, 1994). Through these dimensions, transformational leaders inspire followers to transcend self-interest for the good of the organization and elevate followers' needs from lower to higher levels of maturity (Avolio et al., 2009). The effectiveness of transformational leadership has been demonstrated across various organizational contexts. Meta-analyses by Judge and Piccolo (2004) and Wang et al. (2011) confirmed significant positive relationships between transformational leadership and various indicators of leadership effectiveness, including follower job satisfaction, follower motivation, and leader effectiveness. These findings have positioned transformational leadership as one of the most influential contemporary leadership theories in organizational research.

In the public sector context, transformational leadership has gained increasing attention. Trottier et al. (2008), found that transformational leadership behaviors were positively associated with perceived leadership effectiveness in U.S. federal agencies. Similarly, Wright and Pandey (2010) observed that public organizations are not as bureaucratic as commonly believed and that transformational leadership can flourish in these settings. However, Van Wart (2013) noted that the application of transformational leadership in public administration might face unique challenges due to institutional constraints, suggesting that contextual factors significantly influence its effectiveness. Within project management specifically, Tyssen et al. (2014) examined transformational leadership in temporary organizations, finding that it positively influences followers' commitment to the project. Müller and Turner (2010) demonstrated that the appropriateness of leadership style in projects depends on project type, with transformational leadership being particularly effective in complex and change-oriented projects. However, as Kissi et al. (2013) noted, the effectiveness of transformational leadership in project contexts may be moderated by organizational factors, a finding that highlights the importance of considering the specific environment in which leadership operates.

Employee empowerment has been conceptualized from both psychological and structural perspectives. Psychological empowerment, as defined by Spreitzer (1995), encompasses four cognitions: meaning, competence, self-determination, and impact. Structural empowerment, on the other hand, focuses on organizational practices that delegate power and authority to lower levels of the organization (Kanter, 1993). Both perspectives contribute to a comprehensive understanding of empowerment in organizational settings. Research has consistently demonstrated positive outcomes associated with employee empowerment. A meta-analysis by Seibert et al. (2011) found that psychological empowerment was positively related to job satisfaction, organizational commitment, and job performance while being negatively related to strain and turnover intentions. Similarly, Maynard et al. (2012) observed that empowerment at both individual and team levels contributes to enhanced organizational outcomes, including innovation and effectiveness.

In the public sector, empowerment practices face unique challenges. Fernandez and Moldogaziev (2013) found that empowerment practices in U.S. federal agencies had mixed effects on employee performance, with empowerment focused on providing job-relevant knowledge having positive effects, while empowerment focused on granting discretion showing more complex relationships. Smith and Fernandez (2010) argued that the hierarchical and rule-bound nature of public organizations might constrain empowerment efforts, a perspective that aligns with traditional views of public administration as bureaucratic and centralized. Within project management, empowerment has been recognized as a critical factor for success. Tuuli and Rowlinson (2009) found that empowerment in project teams positively influenced both in-role and extra-role performance. Henderson et al. (2013) demonstrated that empowered project teams showed greater resilience in responding to challenges and changes during project implementation. However, as Leung et al. (2014) noted, the temporary nature of project teams and the often rigid structures of project governance might create tensions in implementing empowerment practices effectively.

The theoretical relationship between transformational leadership and employee empowerment has been well-established in the literature. Kark et al. (2003) proposed that transformational leaders enhance follower empowerment through role modeling, articulating a vision, and providing individualized support. This theoretical linkage was empirically supported by Avolio et al. (2004), who found that transformational leadership positively influenced follower psychological empowerment, which in turn enhanced organizational commitment. Several studies have explored the mechanisms through which transformational leadership influences empowerment. Dust et al. (2014) found that transformational leadership enhances psychological empowerment by influencing how followers perceive their work environment. Men and Stacks (2013) observed that transformational leadership creates a supportive organizational climate that facilitates empowerment. These findings suggest that the relationship between transformational leadership and empowerment is mediated by organizational and psychological factors.

In the public sector, the relationship between transformational leadership and empowerment has received limited attention. Park and Rainey (2008) found that transformational leadership in public organizations was positively associated with empowerment and that this relationship contributed to higher job satisfaction and perceived performance. Tummers and Knies (2013) observed that public sector leaders who exhibited transformational behaviors were more likely to empower their followers to implement policies effectively. However, as Jacobsen and Andersen (2015) noted, the effectiveness of transformational leadership in public organizations might be contingent on the specific institutional context, including political influences and bureaucratic structures. Within project management in public administration, the relationship between transformational leadership and empowerment remains underexplored. Clarke (2010) found that transformational leadership in project teams enhanced team learning and performance but did not specifically examine empowerment as a mediating mechanism. Yang et al. (2011) observed that empowering leadership in public sector projects enhanced team efficacy and performance, but their study focused on empowering leadership as a distinct construct rather than examining how transformational leadership influences empowerment. This limited research highlights a significant gap in understanding how transformational leadership and empowerment interact within the specific context of public sector project management.

Recent studies have begun to address this gap but with mixed results. Aga et al. (2016) found that transformational leadership positively influenced project success in non-governmental organizations, with team building as a mediating mechanism, suggesting that transformational leadership might enhance project outcomes through team-oriented processes similar to empowerment. However, Chipunza et al. (2017) found that the relationship between transformational leadership and employee engagement in South African public sector organizations was moderated by institutional factors, indicating that context plays a crucial role in determining leadership effectiveness.

The present study contributes to this evolving body of literature by specifically examining the relationship between transformational leadership and employee empowerment in Polish public administration project management. By focusing on this specific context, the research provides valuable insights into how leadership and empowerment dynamics operate within the unique constraints and opportunities of public sector project management in a Central European setting.

3. Methods

The article results from a research project financed by the National Science Center (Miniatura 5 number: 2021/05/X/HS4/00171). The research project was designed to gain knowledge on the maturity of local government public administration to implement solutions related to team self-management processes in Poland. The selection of units to be surveyed from the general population was complete; consequently, surveys were planned in 18 offices in the capital cities of voivodeships in Poland. The study covered all 269 departments and faculties. In the beginning, the first questionnaire survey was sent to directors or deputy directors of all departments. Their task was to identify a project that required the involvement of a team with various skills, experience, and knowledge, and to select a person from this team to conduct further research. Managers selected a total of 70 employees (and 70 projects) who met the adopted assumptions. Then a second questionnaire survey was sent to them. A total of 50 responses were received. The choice of where to conduct the research is dictated by city offices that are the capitals of voivodeships should implement advanced organizational and functional solutions in their activities. The designed research was quantitative and was carried out using the computer-assisted telephone interviewing (CATI).

In addition to the author's methodologies, leadership and empowerment scales were used when constructing the survey (Tuckman, Jensen 1997; Super 2020; Turaga 2022). A -2 to 2 scale was used for leadership and empowerment related expressions: -2 = Very Poor, -1 = Poor, 1 = Good, 2 = Very Good. In this regard, the main research questions were evaluated using mean, median, and correlation analysis.

The primary research goal for this paper is to investigate the relationships between transformational leadership and empowerment within the context of project management in public administration. In contemporary project management, successful empowerment between employees and managers is significant in speeding up project activities and improving effectiveness in executing project tasks. Therefore, the study investigates whether transformational leadership enhance empowerment within the context of project management in public administration. One hypothesis and three research questions were formulated (Table 1).

Table 1.
Research questions and hypotheses

Research Questions (RQ)	Hypotheses (H)
RQ1. Is transformational leadership adopted as the predominant leadership style during project management?	H1: The adoption of a transformational leadership style positively enhances employee empowerment.
RQ2: Do managers empower their employees in project management within public administration?	
RQ3: Is there a significant correlation between transformational leadership style and employee empowerment in project management?	

Source: own compilation.

3.1. Research Model

The following diagram (Figure 1) visually delineates the investigator's findings on the relationship between transformational leadership and empowerment.

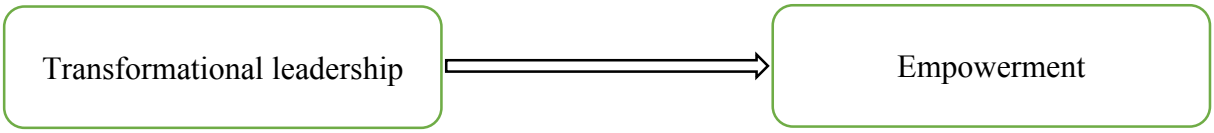

Figure 1. Research Model.

Source: own prepared.

In our research, we used factor analysis because encompasses diverse multivariate statistical methods with the primary objective of elucidating the underlying structure inherent in a given data matrix (Alpar, 2011). To assess the suitability of the dataset, two distinct methods are employed: the Bartlett test (Bartlett, 1937) and the Kaiser-Meyer-Olkin (KMO) test (Kaiser, 1970). The Bartlett sphericity test provides insights into the presence of a satisfactory level of correlation among variables. If the p-value derived from the Bartlett test is below the 0.05 significance threshold, it signifies a notable relationship among variables, indicating suitability for conducting factor analysis. The KMO value, ranging from 0 to 1, evaluates the sampling adequacy and the appropriateness of inter-variable correlations for factor analysis. A KMO value equal to or exceeding 0.50 is considered acceptable, indicating sufficient sampling adequacy (Durmuş, Yurtkoru, Çinko, 2013; Kalaycı, 2014).

The gathered data were analyzed in two ways: exploratory factor analysis using the principal component analysis method and descriptive statistics using the frequency and correlation analyses (Figure 2).

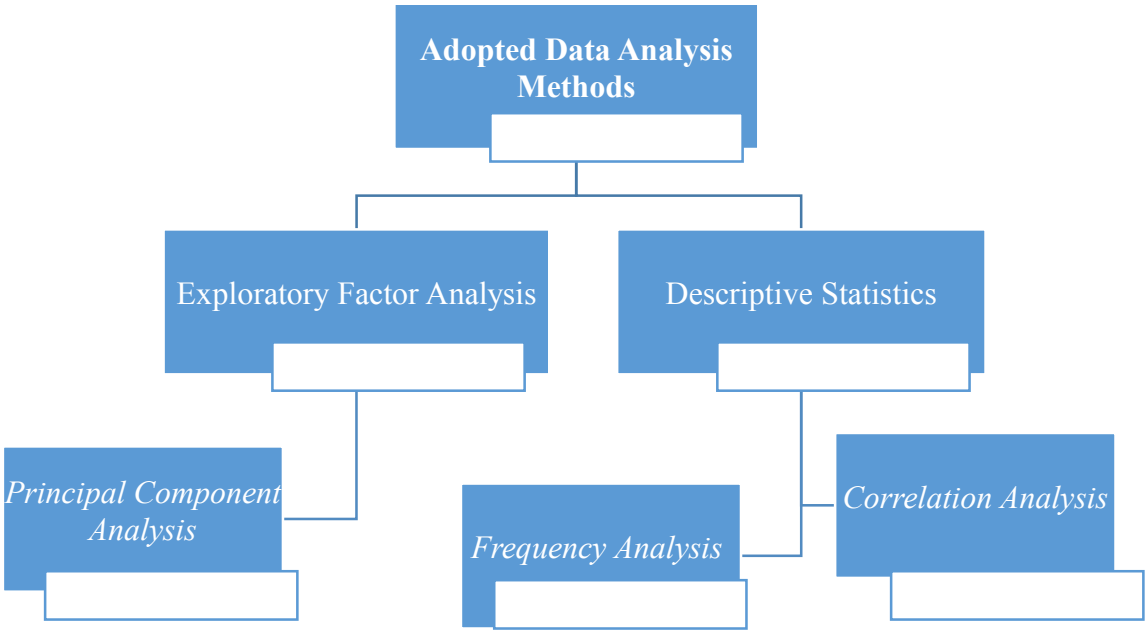

Figure 2. Adopted methods for analysing data obtained from surveys.

Source: own prepared.

4. Results – Exploratory Factor Analyses

In this part, factor analysis will be employed to delineate the underlying structure of the study's data matrix.

4.1. Transformational Leadership

The eligibility of the data for factor analysis was assessed through the Kaiser-Meyer-Olkin (KMO) coefficient and the Bartlett Sphericity test, revealing a KMO value of 0.744 and significant results for the Bartlett Sphericity test ($\chi 2 = 127.480$, $p < 0.001$). Given these outcomes, it was deemed appropriate to proceed with factor analysis for the data about Transformational Leadership construction. To this end, Principal Component Analysis (Pearson, 1901) served as the estimation method, complemented by the Varimax Rotation Method (Kaiser, 1958).

Table 2.
Results of the Exploratory Factor Analysis Related to Transformational Leadership

Corresponding Items	Transformational Leadership
Encouraged employees to come up with their ideas	0.851
Encouraged you to look for better ways of doing things and to come up with your ideas	0.783
He/She was a source of new ideas, thought-provoking; you could learn a lot from him/her	0.747
Encouraged group discussions and implemented solutions adopted by the group	0.741
He/She was a good representative of the interests of the team he was leading towards higher superiors	0.768
Able to defuse tensions and misunderstandings within the team	0.585
Ensured that employees were informed about the goals of the team and their role in the organization	0.504
Total Variance Explained	49.99%

Source: own prepared.

A total of 7 expressions related to the one-dimensional construction in the study were subjected to factor analysis. The analysis revealed the existence of one dimension with an eigenvalue exceeding 1. This dimension accounts for a total variance of 49.99% (Table 2).

4.2. Empowerment

The eligibility of the data for factor analysis was assessed through the Kaiser-Meyer-Olkin (KMO) coefficient and the Bartlett Sphericity test, revealing a KMO value of 0.654 and significant results for the Bartlett Sphericity test ($\chi 2 = 52.095$, $p < 0.001$). Given these outcomes, it was deemed appropriate to proceed with factor analysis for the data about empowerment construction. To this end, Principal Component Analysis (Pearson, 1901) served as the estimation method, complemented by the Varimax Rotation Method (Kaiser, 1958).

Table 3.
Results of the Exploratory Factor Analysis Related to Empowerment

Corresponding Items	Transformational Leadership
The control of the implementation of the tasks was carried out by the employees	0.515
Staff commitment to tasks was high	0.836
Team membership had a motivating effect on employees	0.836
Competence of team members was high	0.772
Total Variance Explained	56.70%

Source: own prepared.

A total of 4 expressions related to the one-dimensional construction in the study were subjected to factor analysis. The analysis revealed the existence of one dimension with an eigenvalue exceeding 1. This dimension accounts for a total variance of 56.70% (Table 3).

4.3. Reliability of Research Instruments

In this part, reliability of the research instruments are evaluated by Cronbach's alpha results.

Table 4.
Cronbach's Alpha results

Instruments	Cronbach's Alpha Value
Transformational Leadership	0.821
Empowerment	0.709

Source: own prepared.

Upon scrutiny of the Cronbach alpha values provided above for the instruments utilized in this study, it becomes apparent that each dimension demonstrates reliability in terms of internal consistency.

In this part, the main research questions and hypotheses are evaluated in the order presented in Table 1. In the following, transformational leadership is evaluated, and results are presented in Table 5.

Table 5.
Evaluation of the leadership style

Corresponding Item	Mean	Median	Skewness	Kurtiosis	Std Dev.
Transformational Leadership	-1.28	-1.42	1.12	0.61	0.57

Note. Std Dev. - Standard deviation.

Source: own prepared.

The result exhibits that transformational leadership is not the predominant leadership style in public organizations (Table 5). In this regard, research question 1 (RQ1. Is transformational leadership adopted as the predominant leadership style during project management?) was negatively evaluated.

Table 6.
Evaluation of the empowerment

Corresponding Item	Mean	Median	Skewness	Kurtiosis	Std Dev.
Empowerment	-1.18	-1.25	1.78	4.45	0.60

Note. Std Dev. - Standard deviation.

Source: own prepared.

The findings indicate that empowerment is uncommon during project implementation (Table 6). In other words, managers in public administration do not actively empower their employees in project management. As a result, research question 2 (RQ2: Do managers empower their employees in project management within public administration?) was negatively evaluated.

In the following, correlation analysis is presented to evaluate the relationship between research variables in Table 7. Tabachnick and Fidell (2013) and George (2011) indicate that If Skewness and Kurtosis's results are between +1.5 and -1.5, it can be concluded that data has normally been distributed. In the study, only the Empowerment variable is unsuitable for this criterion. In addition, when a small sample size is considered, it is seen that non-parametric tests can be appropriate for the study. Therefore, Spearman correlations have been applied.

Table 7.
Evaluation of the empowerment

Variables	Mean	Median	Std Dev.	1.
1. Transformational Leadership	-1.28	-1.42	0.57	0.185
2. Empowerment	-1.18	-1.25	0.60	-

Note. Spearman's correlation applied, n = 50. Std Dev. - Standard deviation.

Source: own prepared.

The findings show that no significant relationship exists between empowerment and transformational leadership ($r = 0.185$, $p > 0.01$). According to correlation analysis results, research question 3 (RQ3: Is there a significant correlation between transformational leadership style and employee empowerment in project management?) has negatively evaluated that there is no significant relationship between transformational leadership style and employee empowerment.

As a result, hypothesis 1 (H1: The adoption of a transformational leadership style positively enhances employee empowerment) has been rejected because there is no significant relationship between related variables.

5. Conclusion and discussion

The research findings above indicate that transformational leadership is not the dominant leadership style in public organisations. Importantly, this applies to project implementation contexts, where institutional constraints typical of the public sector should be less significant, and the project-based approach should encourage using such a leadership style.

Unfortunately, as a consequence of or regardless of the presence of transformational leadership in the studied cases, managers in public administration do not actively empower their employees during project management. It may result in lower-than-possible motivation and engagement among project team members. Employees do not feel authorised to make decisions or responsible for task execution. There may be a gap between current leadership practices in the public sector and the optimal leadership style required for effective project management.

Moreover, the results do not indicate a significant relationship between transformational leadership style and employee empowerment ($r = 0.185$, $p > 0.01$). In other words, the findings revealed that even where a transformational leadership style was applied, it did not positively impact the empowerment of the surveyed employees.

These findings can be understood through the lens of institutional theory and bureaucratic inertia, which provide compelling explanations for the weak empowerment practices observed in Polish public administration. Institutional theory suggests that organizations are embedded in institutional environments that shape their structures and behaviors through normative, coercive, and mimetic pressures (DiMaggio, Powell, 1983). In the context of Polish public administration, decades of centralized, hierarchical governance have created deeply embedded institutional norms that resist change, even when new leadership philosophies are introduced. The concept of bureaucratic inertia further explains why traditional command-and-control structures persist despite efforts to implement more participatory approaches. Weber's (1947) classical bureaucratic model, which emphasizes hierarchy, rules, and formal procedures, remains deeply ingrained in public sector organizational culture. Selznick's (1957) institutionalization theory suggests that organizations develop their own values and character over time, making them resistant to change and creating organizational inertia that maintains established patterns of behavior even when environmental conditions change. This institutional embeddedness may explain why transformational leadership behaviors, when present, fail to translate into meaningful empowerment practices. The formal rules, hierarchical approval processes, and risk-averse culture characteristic of public bureaucracies create structural barriers that prevent leaders from delegating meaningful authority to subordinates, regardless of their leadership intentions.

The research results indicate the need to strengthen empowerment efforts to foster better teamwork. They also indicate investing in leadership development programs that promote leadership qualities such as inspiring and motivating employees, supporting empowerment, and aligning goals with the organisation's mission.

1. Multi-level Leadership Development Program: - Executive level: 360-degree feedback assessments using validated transformational leadership instruments (MLQ-5X), followed by individualized coaching focused on empowerment behaviors - Middle management: Skills-based workshops on delegation techniques, decision-making autonomy, and psychological safety creation - Frontline supervisors: Mentoring programs pairing experienced empowering leaders with developing managers.
2. Institutional Reform Initiatives: - Establish "empowerment zones" within project teams where traditional approval hierarchies are temporarily suspended - Create performance metrics that explicitly reward empowering behaviors and employee autonomy - Implement reverse mentoring programs where junior employees advise senior leaders on empowerment practices.
3. Assessment and Monitoring Framework: - Quarterly empowerment climate surveys measuring Spreitzer's (1995) four dimensions: meaning, competence, self-determination, and impact - Leadership competency assessments using behaviorally-anchored rating scales (BARS) specific to empowering behaviors - Project outcome analyses correlating empowerment practices with project success metrics (time, budget, stakeholder satisfaction).
4. Structural Interventions: - Pilot "flat project structures" that eliminate middle management layers during project implementation - Establish cross-functional empowerment committees with authority to modify bureaucratic procedures - Create "empowerment champions" roles within each department to monitor and support empowerment initiatives.

These interventions should be implemented gradually, with continuous monitoring and adjustment based on empirical feedback, recognizing that institutional change requires sustained effort and commitment from multiple organizational levels.

Public organisations should prioritise leadership approaches that value integrity, transparency, and accountability. Of course, one must not forget the specific nature of public sector operations, including institutional conditions and the goals driven by the need to consider the public interest and meet social needs. Therefore, leaders should also pay attention to the public interest and foster a sense of social responsibility (Trippner-Hrabi et al., 2024).

Participants who volunteered for the study may systematically differ from those who did not, potentially introducing self-selection bias. Additionally, the study may not have accounted for all relevant external variables or contextual factors that could influence the relationship between transformational leadership style and empowerment. Influences such as political

pressure, financial constraints, or changes in public policy may have distorted the results and should be carefully considered in future research.

Finally, on the one hand, it would be worthwhile to conduct studies using a similar methodology in other countries' public sectors to confirm whether the public sector's specific nature limits the impact of transformational leadership on employee empowerment. On the other hand, similar studies in the private sector are also recommended to compare results and generate suggestions for increasing empowerment in public institutions.

References

1. Aga, D.A., Noorderhaven, N., Vallejo, B. (2016). Transformational leadership and project success: The mediating role of team-building. *International Journal of Project Management, Vol. 34, Iss. 5*, pp. 806-818.
2. Alpar, R. (2011). *Applied multivariate statistical methods*. Ankara: Detay Press, pp. 10-29.
3. Avolio, B.J., Zhu W., Koh W., Bhatia P. (2004). Transformational leadership and organizational commitment: Mediating role of psychological empowerment and moderating role of structural distance. *Journal of Organizational Behavior: The International Journal of Industrial, Occupational and Organizational Psychology and Behavior, Vol. 25, No. 8*, pp. 951-968.
4. Avolio, B.J., Walumbwa, F.O., Weber, T.J. (2009). Leadership: Current theories, research, and future directions. *Annual review of psychology, Vol. 60, No. 1*, pp. 421-449.
5. Bartlett, M.S. (1937). Properties of sufficiency and statistical tests. *Proceedings of the Royal Society of London. Series A-Mathematical and Physical Sciences, Vol. 160, Iss. 901*, pp. 268-282.
6. Bass, B.M. (1985). *Leadership and performance beyond expectations*. New York: Free Press; London: Collier Macmillan.
7. Bass, B.M., Avolio, B.J. (Eds.) (1994). *Improving organizational effectiveness through transformational leadership*. London: SAGE Publications, Inc.
8. Burns, J.M. (1978). *Leadership*. New York: Harper & Row.
9. Chipunza, C., Samuel, M.O., Mariri, T. (2017). Leadership style, employee motivation and commitment: Empirical evidence from a consolidated retail bank operating in a depressed economy. *South African Journal of Human Resource Management, Vol. 15, Iss. 1*, pp. 1-9.
10. Clarke, N. (2010). Emotional intelligence and its relationship to transformational leadership and key project manager competences. *Project Management Journal, Vol. 41, Iss. 2*, pp. 5-20.
11. Crawford, L.H., Helm, J. (2009). Government and governance: The value of project management in the public sector. *Project Management Journal, Vol. 40, Iss. 1*, pp. 73-87.

12. Denhardt, J.V., Denhardt, R.B. (2015). *The New Public Service: Serving, Not Steering*. New York/London: Routledge.
13. DiMaggio, P.J., Powell, W.W. (1983). The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. *American Sociological Review, Vol. 48, No. 2*, pp. 147-160.
14. Durmuş, B., Yurtkoru, E.S., Çinko, M. (2013). *Data Analysis in Social Sciences with SPSS*. İstanbul: Beta Publishing (5th Print).
15. Dust, S.B., Resick, C.J., Mawritz, M.B. (2014). Transformational leadership, psychological empowerment, and the moderating role of mechanistic–organic contexts. *Journal of Organizational Behavior, Vol. 35, No. 3*, pp. 413-433.
16. Fernandez, S., Moldogaziev, T. (2013). Employee empowerment, employee attitudes, and performance: Testing a causal model. *Public Administration Review, Vol. 73, No. 3*, pp. 490-506.
17. George, D. (2011). *SPSS for Windows step by step: A simple study guide and reference*. 17.0 update, 10/e. Pearson Education India.
18. Henderson, L.S., Stackman, R.W., Lindekilde, R. (2016). The centrality of communication norm alignment, role clarity, and trust in global project teams. *International Journal of Project Management, Vol. 34, Iss. 8*, pp. 1717-1730.
19. Jacobsen, C.B., Bøgh Andersen, L. (2015). Is leadership in the eye of the beholder? A study of intended and perceived leadership practices and organizational performance. *Public Administration Review, Vol. 75, No. 6*, pp. 829-841.
20. Judge, T.A., Piccolo, R.F. (2004). Transformational and transactional leadership: a meta-analytic test of their relative validity. *Journal of Applied Psychology, Vol. 89, No. 5*, p. 755.
21. Kaiser, H.F. (1960). The Application of Electronic Computers to Factor Analysis. *Educational and Psychological Measurement, Vol. 20, Iss. 1*, pp. 141-151.
22. Kaiser, H.F. (1970). A second-generation little jiffy. *Psychometrika, Vol. 35*, pp. 401-415.
23. Kalaycı, Ş. (2014). *SPSS Applied Multivariate Statistical Techniques with SPSS (6th ed.)*. Ankara: Asil Publishing.
24. Kanter, R.M. (1993). *Men and women of the corporation (2nd ed.)*. New York: Basic Books.
25. Kark, R., Shamir, B., Chen, G. (2003). The two faces of transformational leadership: Empowerment and dependency. *Journal of Applied Psychology, Vol. 8, No. 2*, pp. 246-255.
26. Kissi, J., Dainty, A., Tuuli, M. (2013). Examining the role of transformational leadership of portfolio managers in project performance. *International Journal of Project Management, Vol. 31, Iss. 4,* pp. 485-497.
27. Leung, M.Y., Chan, I.Y.S., Cooper, C.L. (2014). *Stress Management in the Construction Industry*. https://onlinelibrary.wiley.com/doi/10.1002/9781118456361.advert

28. Maynard, M.T., Gilson, L.L., Mathieu, J.E. (2012). Empowerment—fad or fab? A multilevel review of the past two decades of research. *Journal of Management, Vol. 38, Iss. 4*, pp. 1231-1281.
29. Men, L.R., Stacks, D.W. (2013). The impact of leadership style and employee empowerment on perceived organizational reputation. *Journal of Communication Management, Vol. 17, No. 2*, pp. 171-192.
30. Müller, R., Turner, J.R. (2010). Leadership competency profiles of successful project managers. *International Journal of Project Management, Vol. 28, Iss. 5*, pp. 437-448.
31. Nemec, J. (2018). Public administration reforms in Slovakia: Limited outcomes (Why?). Network of Institutes and Schools of Public Administration in Central and Eastern Europe. The NISPAcee. *Journal of Public Administration and Policy, Vol. 11, No. 1*, p. 115.
32. Park, S.M., Rainey, H.G. (2008). Leadership and Public Service Motivation in U.S. *Federal Agencies. International Public Management Journal, Vol. 11, Iss. 1*, pp. 109-142.
33. Pearson K.F.R.S. (1901). LIII. On lines and planes of closest fit to systems of points in space. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science, Vol. 2, Iss. 1*, pp. 559-572.
34. Project Management Institute (2017). *A guide to the project management body of knowledge (PMBOK guide) (6th ed.)*.
35. Seibert, S.E., Wang, G., Courtright, S.H. (2011). Antecedents and consequences of psychological and team empowerment in organizations: A meta-analytic review. *Journal of Applied Psychology, Vol. 96, No. 5*, pp. 981-1003.
36. Selznick, P. (1957). *Leadership in Administration: A Sociological Interpretation*. New York: Harper & Row.
37. Smith, B.L., Fernandez, S. (2010). Equity in federal contracting: Examining the link between minority representation and federal procurement decisions. *Public Administration Review, Vol. 70, No. 1*, pp. 87-96.
38. Spreitzer, G.M. (2008). Taking Stock: A review of more than twenty years of research on empowerment at work. In: C. Cooper, J. Barling (Eds.), *Handbook of organizational behavior* (pp. 54-72). Thousand Oaks, CA: Sage.
39. Spreitzer, G.M. (1995). Psychological empowerment in the workplace: Dimensions, measurement, and validation. *Academy of Management Journal, Vol. 38, No. 5*, pp. 1442-1465.
40. Tabachnick, B., Fidell, L. (2013). *Using Multivariate Statistics. (6th ed.)*. Pearson International. https://elibrary.pearson.de/book/99.150005/9781292034546.
41. Trippner-Hrabi, J., Kam, A., Mokrá, K., Horváthová, P. (2024). Mastering Project Management: the Leader-team Connection. *Scientific Papers of Silesian University of Technology. Organization & Management [Zeszyty Naukowe Politechniki Śląskiej. Seria Organizacji i Zarzadzanie], No. 196*, pp. 547-560.

42. Trottier, T., Van Wart, M., Wang, X. (2008). Examining the nature and significance of leadership in government organizations. *Public Administration Review, Vol. 68, No. 2*, pp. 319-333.
43. Tummers, L.G., Knies, E. (2013). Leadership and meaningful work in the public sector. *Public Administration Review, Vol. 73, No. 6*, pp. 859-868.
44. Tuuli, M.M., Rowlinson, S. (2009). Performance consequences of psychological empowerment. *Journal of Construction Engineering and Management, Vol. 135, No. 12*, 1334-1347.
45. Tyssen, A.K., Wald, A., Spieth, P. (2014). The challenge of transactional and transformational leadership in projects. *International Journal of Project Management, Vol. 32, Iss. 3*, pp. 365-375.
46. Wang, G., Oh, I.-S., Courtright, S.H., Colbert, A.E. (2011). Transformational leadership and performance across criteria and levels: A meta-analytic review of 25 years of research. *Group & Organization Management, Vol. 36, Iss. 2*, pp. 223-270.
47. Weber, M. (1947). *The Theory of Social and Economic Organization*. New York: The Free Press.
48. Wright, B.E., Pandey, S.K. (2010). Transformational leadership in the public sector: Does structure matter? *Journal of Public Administration Research and Theory, Vol. 20, No. 1*, pp. 75-89.
49. Van Wart, M. (2013). Lessons from leadership theory and the contemporary challenges of leaders. *Public Administration Review, Vol. 73, No. 4*, pp. 553-565.
50. Yang, L.R., Huang, C.F., Wu, K.S. (2011). The association among project manager's leadership style, teamwork and project success. *International Journal of Project Management, Vol. 29, Iss. 3*, pp. 258-267.

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ARTIFICIAL INTELLIGENCE AND THE CEO'S PERSONAL BRAND: OPPORTUNITIES, RISKS, AND PARADOXES

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Purpose: This study explores the opportunities and risks of using artificial intelligence (AI) in building a CEO's personal brand.
Design/methodology/approach: The research was exploratory and based on twelve in-depth interviews (IDIs) with CEOs from various industries and company sizes in Poland, conducted between October 2024 and February 2025.
Findings: The analysis indicates ambivalent CEO attitudes towards AI use in the process of building their personal brand. Specifically, these tools are perceived by CEOs as support in content creation, communication planning, and decision-making, but at the same time raise concerns about loss of authenticity, credibility, and image abuse (e.g., deepfakes). As authenticity remains a foundational element of a leader's personal brand and a key factor in building trust with their audience, these tensions highlight the importance of taking an ethically grounded approach to integrating AI.
Research limitations/implications: The main limitation is the small and non-representative sample. Future studies should include more CEOs from different industries and compare gender perspectives. Audience views on CEO authenticity also deserve further exploration.
Practical implications: CEOs should stay personally involved in shaping their personal brand. Authenticity and credibility are essential for maintaining stakeholder trust. The research highlights the need for a cautious and intentional use of AI in personal branding. Organizations should establish clear guidelines to ensure transparency and reduce risks such as deepfakes or content homogenization.
Social implications: The research draws attention to the role of CEOs as public figures shaping social trust. It highlights the societal value of authenticity and responsibility in leadership communication. The findings may inform norms and expectations around transparent and ethical self-presentation in business.
Originality/value: This is one of the first studies to examine AI's role in CEO personal branding. It provides a comprehensive overview of emerging opportunities, risks, and paradoxes, emphasizing the ethical challenges and the need for intentional technology use to sustain trust and leadership influence in the age of generative AI.
Keywords: CEO, personal brand, artificial intelligence (AI), opportunities, risks, paradoxes.
Category of the paper: Research paper.

1. Introduction

The concept of personal brand has been present in management practice for almost three decades (Peters, 1997), not much shorter in the scientific discourse in other disciplines. However, recognition of the CEO - or any organizational founder or leader — as a central figure has a much longer history. The CEO's attitude toward social, economic, or technological changes and his or her activity toward such changes influence the direction of change in the organization he or she leads. Often, the CEO of an organization plays a crucial role in driving transformations that, over time, can be groundbreaking for communities of all sizes.

The distinctive CEO personal brands of individuals such as Henry Ford, Michael Dell, Bill Gates, Mary Kay Ash, Oprah Winfrey, Steve Jobs, and Richard Branson enhanced their organizations' recognition, credibility, and value. The target groups, products, services, and benefits offered by these companies are very diverse, however, the influence of the CEO's personal brand is clearly visible. It contributes both to the organization's success and to the socio-economic changes to which the organizations are linked, in one way or another.

The connection between CEO attitudes and broadly defined socio-economic or technological changes is one of the inherent characteristics of highly individualized, modern Western societies, emphasizing values such as personal self-esteem and personal fulfilment (Cottan-Nir, Lehman-Wilzig, 2018). In atomized societies, distinctive individuals, including those leading various organizations as CEOs, are a source of widespread social influence.

One of the technological changes seen today is the rapid increase in the availability of tools based on artificial intelligence (AI). And the pace of change fits perfectly with the description of reality in terms of the B.A.N.I. world—fragility, anxiety, non-linearity, and incomprehensibility (Grabmeier, 2020; Le Roux, Lucinda, 2022). Although the first visions that humanity would be accompanied by intelligent machines in the future appeared in the 17th century with Descartes (Descartes, 1637), the second half of the 20th (Turing, 1950) and the early 21st century can be considered the beginning of major changes. Tools based on AI or using it to some extent have been in everyday use for many years (e.g., Siri or Alexa). However, it was events such as the Deep Blue program's chess win against Garry Kasparov in 1997 and AlphaGo's victory over Lee Sedol in 2016 that signaled the coming change. Meanwhile, the release of ChatGPT in 2022 became the moment when any person with access to a smartphone or computer and the Internet could independently have a conversation-like interaction with the app. From this moment on, there has been almost constant discussion about what impact AI has and will have on our work and daily life, the boundaries of its application, and the ethical and legal issues that must be addressed (Di Battista et al., 2025; Jurga, 2025). CEO personal brand-building activities are no exception.

Attitudes toward the ways and purposes of building a CEO's personal brand vary, as do attitudes toward implementing AI solutions. CEOs' attitudes toward the use of AI in personal brand building and its broader impact on their understanding of personal branding have not yet been studied. Considering this gap, the following research question was formulated: what opportunities and threats do CEOs perceive regarding AI in the context of building their personal brand?

This paper offers an original contribution as one of the first studies to investigate the role of AI in CEO personal branding. It provides an in-depth analysis of emerging opportunities, risks, and paradoxes, highlighting the ethical challenges and the need for responsible use of AI to sustain trust and authenticity in leadership in the era of generative AI.

The remainder of this article is structured as follows. Section 2 presents the literature review. Section 3 describes the research method based on in-depth interviews with CEOs. Section 4 presents the findings, structured around identified opportunities, risks, paradoxes, and ethical challenges. Section 5 discusses the results. Section 6 concludes this article by presenting its practical implications, limitations, and directions for future research.

2. Literature review

2.1. CEO's personal brand

The CEO's personal brand is now recognized as one of the key factors shaping an organization's value and is increasingly seen as essential rather than optional (Fetscherin, 2015; Scheidt et al., 2018; Cottan-Nir, 2019; Macalik, 2023). Often, the CEO is the face of the company (Love et al., 2017). Trust in an organization does not function in isolation from trust in the CEO (Ingenhoff, Sommer, 2010), and the same is true for reputation (Love et al., 2017), or the perception of an organization through the CEO's perception in the media (Górska & Mazurek, 2021).

A personal brand is defined in many ways:

1. cognitive or emotional effect-focused approach - these definitions emphasize the importance of the branding action effect in the brand audience's minds (e.g.: Omojola, 2008; Parmentier, Fischer, 2012; Gander, 2014; Evans, 2017; Ghorashi et al., 2019),
2. resource-focused approach - the authors target the analysis of knowledge, skills, life history, or activities of an individual who undertakes the personal branding process (e.g.: Kowalczyk, 2020; Mantulenko et al., 2020; Wijaya et al., 2021; Muszyńska, 2022),

3. goal-focused approach - here both definitions and analyses are focused not only on personal brand resources or the cognitive and emotional effects these resources can produce - above all, the importance of conscious management of personal potential in achieving the set goals is emphasized here, and these can be formulated in very different ways (e.g.: Hearn, 2008; Kucharska, 2017; Gorbatov et al., 2018).

A CEO's personal brand is usually not distinctly defined Therefore, it can be assumed that it is *a person associated with a specific organization, directly influencing crucial decisions made in that organization and consciously taking actions to identify, produce, and communicate through self-narration the values by a specific recipient group (e.g., employees, customers, business partners) can be considered to most fully satisfy their needs* (com. Walczak-Skałecka, 2022, p. 114). Both the value provided by the CEO and the needs of the audience can be about functional solutions, relationships, emotions, knowledge and many other areas.

The CEO's influence on the operations of the organization takes place on many levels - from making key decisions, to shaping the organizational climate and culture, to representing the organization outside its walls. This involves several competencies that a CEO should possess, a certain value system, as well as other characteristics that enable him or her to perform such diverse tasks. The conceptual CEO personal brand equity model (Figure 1) assumes a cascading relationship between three categories of factors that shape this equity. The first level is the CEO's brand assets, including but not limited to value system, authenticity, or consistency. These resources are used to create the second category parameters - stakeholder perceptions and behaviors. The third level is the perceived added value (Cottan-Nir, 2019).

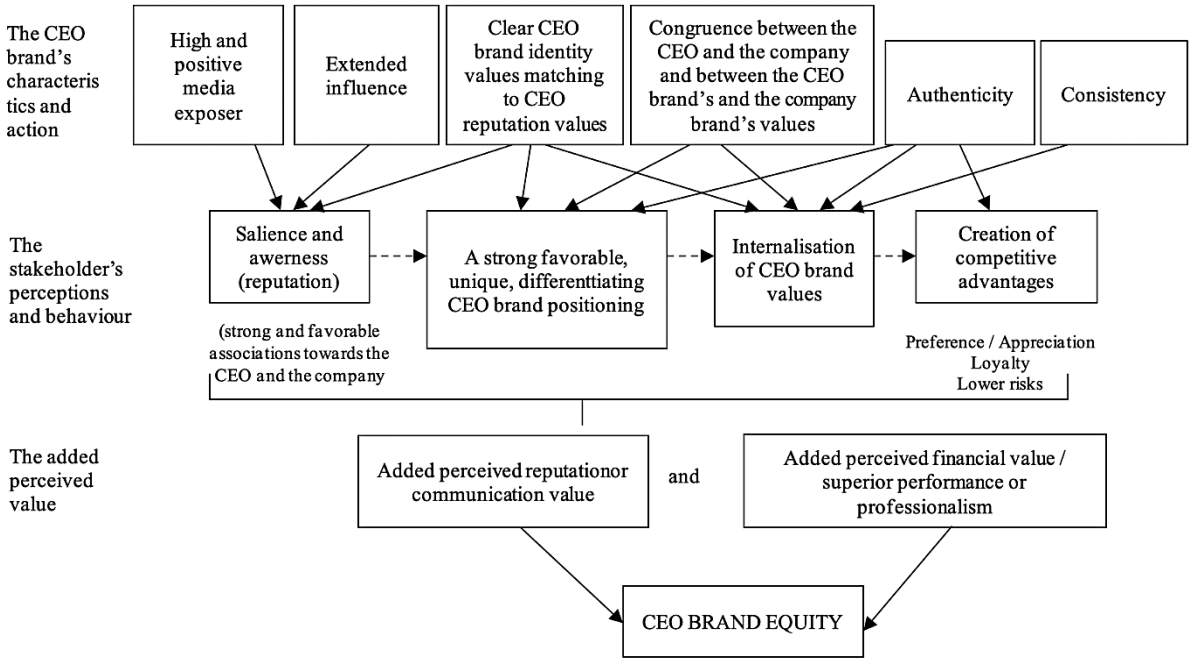

Figure 1. The funnel model of CEO brand equity.

Source: Cottan-Nir, 2019, pp. 121-133.

Core values, authenticity, and coherence form the foundation of CEO brand equity. They shape the CEO's attitudes toward various phenomena and directly influence the effectiveness of leadership in achieving the organization's intended outcomes.

The CEO's brand can also be analyzed through the prism of the organization's brand advocate (endorsement), where the strongest emphasis is placed on leveraging the CEO's community potential, similar to what happens in the case of collaborations formed by product brands with celebrity brands. In this approach, the CEO and his or her personal brand play the celebrity role (Scheidt et al., 2018). This is an interesting observation since the techniques that celebrities use in their public and media activities are quite different from those that are most often used in the expert model of personal brand (Walczak-Skałecka, 2022), while very often using the same communication channels and tools. These techniques are inseparable from the audience expectations, which also differ significantly between the audience groups of an expert personal brand and a celebrity brand.

People who manage organizations naturally have an impact on different social groups. Sometimes, this influence is limited to a small group of employees, their families, customers, and sometimes the local community. For corporate managers, this influence is much broader. The CEO building his or her personal brand can consciously and deliberately influence huge numbers of people. Potentially, the CEO is no longer just participating in change but can be a source of social change. People holding this position use these opportunities in different ways, some actively trying to influence social and even political issues that are not always directly related to the interests or values represented by the organization they lead (Hambrick, Wowak, 2021; Olkkonen, Morsing, 2023; Wowak et al., 2022). The personal brand today is an instrumentation that facilitates achieving such goals (Barros et al., 2025). Like any tool, the CEO's personal brand can be used for purposes other than as an agency for positive social change.

2.2. AI - opportunity or threat to building a CEO's personal brand?

The development of artificial intelligence will undoubtedly change many human activities. Ironically, it may be the capacity to maintain genuine relationships not mediated by technology that becomes the true strength and value, particularly for a CEO's personal brand. While AI offers significant opportunities to increase visibility and engagement, it also comes with risks that can undermine the trust of both CEOs and the organizations they represent. In this context, it is worth considering how AI supports building the CEO's personal brand and what challenges it presents.

One of the key areas in which AI supports leaders is communication automation, resulting in increased productivity. For example, AI can generate recommendations for expert article topics or suggest the best time to publish social media posts (Grewal et al., 2020). Machine learning-based tools also analyze audience responses and suggest the most effective ways to interact. Moreover, language models such as GPT-4 (OpenAI), Claude 3 (Anthropic),

or Gemini 1.5 (Google DeepMind) facilitate the creation of high-quality content, helping leaders write industry articles, posts, or even public speaking scripts. Such solutions save time and ensure consistency in communications, enabling leaders to adapt their message to appropriate audiences better (Buck, Marrow, 2018). However, artificial intelligence-based productivity that brings significant opportunities also comes with risks.

One of the main risks is that AI-generated content will be too schematic and out of context and personal character. Artificial intelligence is prone to significant errors, such as "hallucinations" - generating incorrect or misleading information - and losing control over tasks during execution. These are not qualities usually associated with effective leadership, especially in a role that requires accountability, balancing the interests of multiple stakeholders, analyzing historical trends, detecting subtle changes in the marketplace, and making strategic decisions that shape the company's future (Doh, Quigley, 2014; Freeman, 2010). In an era of increasing demand for authenticity and valuable relationships, a lack of personal commitment to communication can undermine trust in the leader (Harvey et al., 2006).

With AI development also comes content falsification and image manipulation risks. Algorithms can generate realistic deepfakes - fake video and audio recordings that can be used to spread disinformation (Przegalińska, Jemielniak, 2023). For business leaders, this can lead to image crises and damage to stakeholder trust (Chesney & Citron, 2019). One issue to consider is the ethical use of AI in building a personal brand. If a CEO relies on AI-generated content without verifying and correcting it appropriately, they may expose themselves to accusations of lack of transparency. Today's audiences expect sincerity and authenticity, so failing to disclose the AI's role in communications can be perceived as manipulation (Klenk, 2024). Creating substantial and engaging content requires diligence, care, and time, along with a proper content strategy set in context.

In conclusion, generative artificial intelligence is already an integral part of our lives, and over time, perhaps it will become more and more like ourselves. It is a tool that is increasingly used, but it will always require careful consideration of its use. The key is to find a balance between technology and an authentic, human message. Ultimately, it is authenticity and values, not algorithms, that build strong and lasting leaders' personal brands.

3. Methods

Widespread access to AI has become one of the central topics in public discourse and scientific research.

However, given the relatively recent emergence of this phenomenon, research on the relationship between AI and the CEO's personal brand remains limited. The authors found no prior studies specifically addressing the use of AI in building a CEO's personal brand, which

indicates a gap deserving closer academic attention. The absence of established literature in this area positions the present study as exploratory in nature. Accordingly, the research question focuses on CEOs' attitudes toward the use of AI-based tools in building personal brand. Moreover, the study aims to explore the opportunities, risks, and paradoxes associated with leveraging AI in building a personal brand.

To achieve the research objective of identifying and understanding the opportunities and risks of applying AI in building a CEO's personal brand, an individual in-depth interview (IDI) method was used. This method thoroughly examines the studied phenomenon and provides a personalized perspective on the subjects affected (Alvesson, 2003). Given that personal branding is a subjective phenomenon, it is important to examine it through the perspectives of individual actors (Vallas, Christine, 2018). This argument justifies the choice of the in-depth interview method in the context of our paper.

The study was designed as a pilot, serving as an introduction to a broader research project focused on understanding CEO attitudes and their perceptions regarding the use of AI-based tools in building a personal brand, along with the internal dynamics of these attitudes. This type of research offers an initial examination of the phenomenon and helps identify areas for further inquiry (Grzeszkiewicz-Radulska, 2012). The study employed purposive sampling. The sample consisted of 12 CEOs managing organizations of varying sizes, which served as the primary selection criterion. An additional condition was the presence of an active LinkedIn profile, as the platform is commonly used for personal branding among managers and leaders (Venciute et al., 2024). Participant characteristics are summarized in Table 1. Given the small sample size, the findings are not intended to be generalizable. Partially structured interviews contained mostly open-ended questions, which allowed the respondent to speak freely and better understand their perspective. The generally accepted structure enables data obtained from individual respondents to be compared with each other (Glinka, Czakon, 2021). The interviews were conducted using ICT techniques and ranged in length from 30 to 50 minutes.

All respondents provided informed consent for the interviews to be recorded and transcribed. The interviews were conducted between October 2024 and February 2025.

Four initial themes emerged during the coding stage in response to the research questions: 1) the opportunities created by AI in building the CEO's personal brand, 2) the threats posed by AI in this process, 3) the paradoxes that AI causes concerning building the CEO's personal brand process, and 4) the future of the CEO's personal brand in AI's era.

The collected data were coded and analyzed using MAXQDA software. To protect participants' anonymity, all identifying information – such as names, surnames, and organizational affiliations - was removed.

Table 1.
Detailed data on the interviewed group of managers

Code	Position	Gender	Number of employees	Sector
Id1	Professional CEO	M	11-50	Technology
Id2	Professional CEO	M	2-10	Technology
Id3	CEO, owner	F	51-250	Development services
Id4	CEO, co-founder	M	51-250	Marketing communications
Id5	CEO, founder	M	>250	Vehicle rental
Id6	Professional CEO	F	>250	Food industry
Id7	CEO, co-founder	M	2-10	Logistics
Id8	CEO, founder	M	51-250	Dietary services
Id9	Professional CEO	M	11-50	Business consulting
Id10	CEO, founder	M	11-50	Business consulting
Id11	Professional CEO	F	>250	Business services
Id12	CEO, founder	M	51-250	Real estate brokering

Source: own elaboration.

4. Results

The discussion of results is structured around the main themes that emerged from the data. It also highlights issues that require further investigation.

The first important observation is the heterogeneous understanding of personal brand concepts and the different levels of engagement in such activities among individual respondents. This theme is not developed in the results presented, but it provides a starting point for potential interpretations of the other statements. This is also an interesting area to explore in future research. Respondents' attitudes towards the building of the CEO's personal brand process using AI by men and women also differed. The statements lacked coherence, but even some directly contradicted each other. Thus, building a CEO's personal brand is not gender-neutral (Staniszewska, Górska, 2021). Therefore, it seems important for future research to explore how AI shapes CEO branding through a gendered lens.

AI as an Opportunity in Building a CEO's Personal Brand

All participants confirmed that AI can be a good support in building the CEO's personal brand path. However, the respondents use these tools with different intensity and scope. AI most often supports communication activities, including content creation and planning. It can also serve an advisory and operational role, freeing up leaders' time for activities that require their personal involvement.

CEOs are increasingly utilizing AI for content generation, including social media posts and more complex documents. Respondents' statements highlight the diversity of AI applications in this area:

Create some texts and I simply have some kind of chat created, which is somehow filled with my knowledge, or from my book, my history. (Id8)

I already use GPT chat for a great deal of the content I create, writing emails, meeting summaries. (Id1)

It's worth noting that AI not only generates content but also helps create outlines, communication plans, and building personal brand strategies:

The very fact that it can plan the whole process of building a brand, strategies some educational. You can play over it and try to use it, it is able from the vast knowledge, which let's say is lacking in some areas, it can suggest some things. (Id9)

I think it will also be able to, based on, just all the data available, build these strategies on the personal brand of specific people, yes, specific activities. (Id11)

I use it to prepare presentations in the context of building outlines. (Id7)

AI's support for time-consuming and not-perceived-as-critical activities allows it to free up the time needed to perform tasks that AI can't do for any human today:

Artificial intelligence can then help us, in creating this visual part, in giving some research, in checking, for example, this research, or some other fact, and the way, we will prepare thanks to the fact that it will help us in that sphere, we also have more time to prepare ourselves for the presentation, for the way of presentation, for what we want to include, what we want to make exactly the plan of such a presentation, well, in this case, I think it could help. (Id3)

However, AI can also support building the CEO's personal brand in areas beyond communication, such as decision-making, including where the CEO builds his or her effectiveness, which is one of the most important attributes of the CEO's personal brand:

AI is not just GPT chat and a language model for creating content on LinkedIn, it is a set of tools that can replace us in some way several functions that until today, for example, took us days, or weeks of work. I mean meta-analysis of data, very large amounts of data, helping us to make appropriate decisions based on data, for example, this was, were in a way management elements reserved only for geniuses. (Id7)

To such strategic thoughts and decisions to bounce your thoughts off each other, because I think that when you talk to anyone, you get to something further at all, even you could talk to a wall, and I think that by throwing out certain thoughts simply and having a conversation, you sort of move forward. And here, however, someone else is bouncing that ball back to you, throwing something into that garden of theirs, as it were, and what causes you to have something to. (Id8)

Another support area that emerged from the data is relationship management, the importance of which for building a CEO's personal brand emerged from many respondents. AI can be used here, for example, to facilitate planning, remind people of important relationships, and streamline ongoing communication:

Relationship building, of course it's talking, coffee and so on, but often it's just staying in touch, so, so any AI-based tools that show really where we are [in that relationship] are important. (Id11)

Artificial intelligence, on the other hand, could [...] answer simple questions or conduct simple correspondence, so if the CEO can use artificial intelligence for that, by all means. I don't do that at the moment, because I still manage to answer various topics myself, but I suspect that in a while, there will be too much of that already, so artificial intelligence would come in handy, and I know that some people already use it for that. (Id5)

CEOs recognize an opportunity to connect with a diverse and widely dispersed audience through their personal brands, which AI can facilitate much more easily:

The important differences are in terms of the opportunities that the online channel gives us in terms of, firstly, scaling this our personal brand to foreign markets simply, and secondly, connections precisely with technology, that is, with AI, which we are increasingly exploring, also the opportunity to be with your brand simultaneously in many places. By this I mean such active knowledge sharing in the form of various video content, courses, training courses, speeches, which are prepared and then played in different places, often at the same time, because some market situation requires it. (Id2)

The group also perceives that AI can significantly reduce the anxiety associated with building a CEO's personal brand. Additionally, it can support individuals who, due to limited resources, are currently engaged in building a CEO's personal brand to a small extent:

These people [CEOs] that I meet on my path, who are just so interesting, and it would be nice to show them. Often they have a problem with how they should describe this brand, how to translate it just into communication. They make themselves such a chat room, such a sparring partner, it helps them build this awareness of what they could show or, what they should show. (Id10)

I see a big opportunity for people who up to now didn't know how this personal brand should be built, if they use these tools to support themselves and not just from them and not like completely, like using them to give them responsibility for this personal brand communication. (Id10)

Many [CEOs] have, really cool things to share, but they don't have the talent, for example, the writing talent, or they don't have the ability to have a team at their place to help them, yeah, that's kind of how it is with me. I don't have writing talent either, I just sometimes know what I want to write, so what I want to say, and I just have a team to help me yeah, or AI. (Id11)

Acceptable and Unacceptable Uses of AI for the CEO Personal Brand

Respondents generally see AI as a useful tool in building a personal brand, but they set clear boundaries on where its use remains appropriate. These boundaries depend largely on personal values and views on leadership.

For many, AI works well when it supports technical aspects, such as organizing speech, improving the language flow, or providing inspiration through brainstorming - but should not take over content creation.

For many people [AI] is able to, it helps to structure the speech in a certain way, it can be a source of inspiration, and that's where it should stop. (Id7)

Others stressed that AI is acceptable as long as the final messages still reflect the CEO's own thoughts and emotions:

For me AI only, then it makes sense if what it creates is, I feel that it is, was my intention, my emotions, that I want in this way, not to make it guess. (Id12)

Several respondents noted that while AI can assist in content preparation, it cannot replace the CEO in public and relational roles, such as conferences, interviews, or personal interactions.

In fact, artificial intelligence can be used to build a personal brand. Whereas artificial intelligence won't go to a conference for us, no, it won't do some video for us, it won't answer in an interview, but for that it can use the text and the thought that the keynote that the CEO has and he would like to form in some, in some elegant way then artificial intelligence could help in that. (Id5)

Artificial intelligence is artificial, so how is it supposed to help make relationships truly human [...]. Ideally, the CEO should not use artificial intelligence too much. Well, because if it does the work for him, it will not be a consistent CEO. The CEO should show directions, be creative and have a vision, and talk about his visions, about what, what he wants to carry out, but also with what people. (Id5)

Regardless of the extent to which the CEOs are already using these tools, they acknowledge that these tools are likely to become an integral part of everyone's daily work. The exception, at least today, is the group of CEOs choosing to build their personal brands based on deliberate non-participation in the technological discourse, that is, based on a complete lack of presence on social media platforms, and today also cutting themselves off from using AI tools.

AI as a Risk in Building a CEO's Personal Brand

CEOs today perceive significant risks associated with the improper use of AI tools and their potential consequences, which could undermine CEO credibility and authenticity:

The dangers are that people will use the available tools in a completely unthinking and unreflective manner. (Id7)

The biggest danger I see is that there will be a rash of these very similar people who are inauthentic. (Id10)

Image theft represents a distinct category of threats. For those leading smaller and larger organizations, credibility or the image of being an expert in some specific area is an important attribute of a CEO's personal brand:

Using the image and through AI generating pornographic content, and as if the most normal blackmail, especially of high-profile people. (Id11)

AI, by increasing the efficiency of certain processes, can also become a tool that will eventually lead to a complete flooding of the communications space through low-value content or the rapid growth of CEO personal brands just by the intensity of their activities:

It seems to me that there is an excess, I mean if I look at LinkedIna for myself, well, there is a lot of this communication there. And it seems to me that it will be increasingly difficult to stand out, that's one. And two, that such blind copying of what artificial intelligence also tells us, after some time will simply cause that we will be flooded by a wave, very similar to each other people who write in a similar way by the fact that they use the same tools. (Id10)

There is also the possibility that the personal brand will no longer become just an instrumentality that supports real-world individuals in achieving their goals. Instead, it may become feasible to manage entirely artificial personal brands, where the interests or intentions of those overseeing them are not straightforward to interpret:

Soon it will be possible to create, as if personal brands, already there are probably such personal brands that do not exist at all only, which are some total creation just based on artificial intelligence. (Id8)

One of the most common threats identified was the loss of credibility regarding the individual CEO's brands and the trust in communicating with others:

I see such a danger also on the side of people's trust, in general, in this content on the Internet by the fact that it will not be fully clear what it publishes, what is behind it, what interest it is supposed to have from it, so this trust, so to speak, social, which seems to me to be declining anyway, has been declining recently [...] will decline. (Id8)

Authenticity in the Context of AI and CEO Personal Brand

The interviews revealed that authenticity occupies a central role in the process of building a CEO's personal brand, yet it is not a uniform construct. Respondents referred to authenticity in at least three interrelated dimensions.

First, authenticity was linked to the reliability of the content, which means that the information shared with the audience comes from a real CEO and hasn't been made up or changed by AI technologies. Participants often talked about how synthetic content, especially deepfakes or AI-generated avatars, could hurt trustworthiness:

Someone might get the idea: I'll record myself here, take a picture of myself, and let the artificial intelligence already make a video of it. And it will use my image to make me say something for a minute, laugh. And it just did it in an elegant, professional way. And the problem is that it won't be real, it will be artificial. And building such artificiality, will cause a very big split between the real person and the one shown by the artificial intelligence in such fake videos. (Id5)

Second, authenticity was defined as personal ownership and self-expression, highlighting the CEO's active participation in creation of content. Several participants emphasised the significance of personally writing texts and featuring in audiovisual materials, rather than assigning these responsibilities to AI systems or avatars:

Well, first of all, 100% authenticity. For me it's 100% texts written by me, eventually corrected by say, yes a copywriter, 100% videos are me on them, not artificial intelligence. (Id4)

Third, authenticity had ethical consequences as it pertained to the distinction between assistance and substitution. Respondents recognised AI's technological ability to accurately replicate human presence but expressed worries over its ethical eligibility when it substitutes the CEO's real persona in interpersonal communication:

On the one hand, AI can help us, but on the other hand, it also kind of, like, obscures the image, in the sense that there will be, there will be, and I see more and more different videos, and even apps that are able to create videos, based on an avatar, whether it's our avatar or an artificially created avatar that pretends to be human, and it pretends to be human very well, so someone can think that they are, that they are such a real person. (Id3)

Furthermore, respondents recognised that specific elements of leadership communication, like empathy, engagement, and drive, remain difficult to replicate through AI technologies. They believe that these relational characteristics that can't be transferred make the CEO's personal brand even more important in leadership roles:

There, where a machine will not replace a human in showing people empathy, warmth, building emotions and building motivation, so artificial intelligence will do well where there are distributed environments and people are in remote positions, for example. But wherever there are people present at work, then artificial intelligence still has a big area to cover. And it is in this engagement of people at work, building loyalty, that the real CEO is essential, and this is where artificial intelligence will lose. (Id5)

Consequently, respondents emphasized that AI should remain a supportive tool, rather than a substitute for personal engagement in brand building.

Regardless of the time, and now as there is AI, you have to remain authentic, and remain yourself, and just use the tools, because the tools are there to help us, not hinder us, as if not to sink into it so without thinking, so to speak. Well, because then you can just turn not where you need to turn. (Id11)

Ethical and Legal Concerns in Building a CEO's Personal Brand with AI

One of the primary ethical issues mentioned by respondents is authorship recognition. Respondents worried about attributing AI-generated content to themselves, emphasising the value of human authorship in personal brand building:

It's I think that such, such ethics and also all these materials that are created, e-books everything that I create should be my authorship. And not authored by AI. And people sign off on it. That's just the way it works, no. Because, and I think that's the direction it's going to go, unfortunately, because it's just not profitable for anyone to write a 300-page guide, no. (Id4)

The perceived unethical nature of claiming authorship over AI-generated content was a recurring theme. While respondents acknowledged the usefulness of AI as a supportive tool, they clearly distinguished between using AI for assistance and attributing AI-created material to oneself:

I'll say it again is that someone will use artificial intelligence to prepare for some speech, but it will verify, and it saves a lot of time, I have no problem with that. But if someone creates materials and signs his name, and he didn't do it, and it's still pulled with artificial intelligence, it uses knowledge from other sources, because it uses so from the content that is available well then that's not really so, that's what I don't, I don't agree with. (Id9)

Another significant ethical and legal concern is the confidentiality and security of data used by AI-based tools:

The biggest challenge in using artificial intelligence in building a personal brand is confidentiality. To get a valuable response, I have to share data about myself, but I'm not sure how it will be used. Even if I buy access and indicate that I don't want to share information, it still raises concerns - especially since one of the largest AI systems is overseen by Elon Musk. You can, of course, act on general patterns, but that's less efficient. (Id6)

In the studied group, despite the numerous risks identified - some of which are ethical - these risks were not interpreted as such, nor were they a topic of consideration or interest. Instead, ethical issues were often viewed merely as components of the legal regulations that lawyers should adhere to:

I rarely, rarely consider these things [ethical] in this particular sense, but we have one law firm that handles both rodo topics and sort of legal topics for us. So everything always goes to them anyway, and I just sleep soundly to myself, because I know I have them for that. (Id8)

For some participants, reflections on ethics emerged only indirectly and were usually associated with broader values such as authenticity rather than specific AI-related ethical dilemmas:

I didn't really, I honestly thought about it [ethics in the context of personal brand and AI] saying instead, for sure, as I mentioned, this authenticity is important, and here ethics or artificial intelligence is behind or not, it's here, it's just ultra important, so that it is. (Id11)

However, on the other hand, ethical issues were simply excluded from AI activities and were more closely associated with the attitudes of the people using these tools:

I don't connect AI with whether someone will be ethical or not. If someone is unethical, they will be without AI as well, and with AI they will be. (Id11)

AI can be, truth be told, a very cool shaving tool, and it can be, on the other hand, a razor in the hand of a monkey. (Id12)

The Paradoxes of AI in Building CEO's Personal Brand

Leaders have many tasks to fulfill, which can sometimes seem to compete with one another. This reflects the AI's use in the process of building their personal brands and the constant balancing act between experimentation, openness to change, and responsibility for how these experiments are conducted:

High-ranking managers, leaders, should be prepared to be able to see both the bright and dark sides of what the use of artificial intelligence technology involves. And this should be part of their image in the industry, in short, managers who position themselves in opposition to this change, in my opinion, will simply be marginalized. (Id7)

Respondents appear to view the role of the CEO as a change leader who must quickly learn how to use AI effectively and safely, and the change seems inevitable.

It is worth taking advantage of many things that from many solutions and opportunities that AI gives us, and I think people will need such tips, such guidance from these real authorities, from real people, we will certainly often use, somewhere from a chat room, from some hints, but there will be rather, a lot of such industries that, well, which, however, require, such a human response, more such, also not dehumanized. (Id3)

The role of a change leader is primarily to set the direction and boundaries of human-AI collaboration in specific organizational contexts.

One of the leader's key competencies is to follow trends, simply to build a workplace in the right way that you just want to come to, this innovation was, is and will be very important, and now, probably more important than ever. (Id11)

It's also a huge responsibility, so that artificial intelligence doesn't create stupidity for us, if we will, if it creates anything for us, and supports it, well that's great, but the ultimate truth, such gap checking, approval and correction, verification, well that, well that has to be [on the CEO's side]. (Id12)

Personal competence and attitudes are gaining importance in every dimension.

A person who wants to manage artificial intelligence, or, someone else's should also have some intelligence. (Id12)

Respondents' statements also reveal paradoxes associated with AI use in building a personal brand. On the one hand, as already mentioned, there is a risk of flooding communication channels with low-quality content of questionable authenticity. Conversely, it offers a chance to appreciate the genuine human aspect of the relationship and the authentic, albeit imperfect, CEO image:

I would say that there is a chance to humanize this image more, because where there will be authenticity, where there will be real thoughtfulness, and these emotions will be able to be a little bit, to disenchant this image of such a strong CEO or strong women CEO, and this is the space precisely for these soft competencies that can be part of building a personal brand. (Id7)

The paradoxes that emerged from the collected material can be summarized as follows:

1. The paradox of automation vs. authenticity—the more effective a CEO's personal brand becomes thanks to AI, the greater the risk of losing its authenticity and credibility.
2. The paradox of democratizing access to personal branding tools through AI vs. homogenization of communication – AI increases the accessibility of personal branding, but it can lead to a loss of uniqueness.
3. The paradox of presence vs. absence – AI enables the CEO to be "present" in many places at once (e.g., video appearances, posts, webinars). However, this presence is often synthetic, devoid of contact with the real person. The CEO is everywhere and nowhere at the same time — his or her presence is ubiquitous, but increasingly less human.
4. The paradox of control vs. loss of control — tools that are supposed to support image control can also become a source of threats and manipulation.
5. The paradox of transparency vs. illusion — masking the actual level of engagement can lead to a lack of ethical and personal transparency.

5. Discussion

This study explored how CEOs perceive the opportunities, risks, and paradoxes related to the use of AI in building their personal brands. The analysis of in-depth interviews with twelve CEOs confirmed that AI offers valuable support in areas such as content creation, communication planning, relationship management, and decision-making. At the same time, respondents emphasized that these benefits are accompanied by significant risks, particularly concerning the potential loss of authenticity, credibility, and trust, core elements of effective personal branding for organizational leaders. The concerns expressed by the surveyed CEOs align with earlier research underscoring that trust in leadership is pivotal, and this trust, in turn, shapes confidence in the organisation as a whole (Ingenhoff, Sommer, 2010; Love et al., 2017). A perceived lack of personal involvement in communication can undermine trust in the CEO (Harvey et al., 2006).

The widespread access to AI-based tools on a large scale is a good example of the dynamics and perception of the world, which can be analyzed through the prism of the B.A.N.I world (Grabmeier, 2020; Le Roux, Lucinda, 2022). The results presented indicate that AI is a dual-purpose tool: on the one hand, it assists leaders in the organization and distribution of content, increasing the efficiency of communication management, and on the other, it raises questions about the authenticity, credibility, and limits of its use. Process automation, while allowing for the optimization of communication activities, can at the same time lead to the homogenization of the message and weaken leaders' individuality (Lair et al., 2005; Love et al.,

2017; Ingenhoff, Sommer, 2010), and the very involvement of AI in this process can be seen as manipulation (Klenk, 2024).

Ironically, the social skills we now consider typically human are becoming more important due to the development and spread of AI. In addition to proficiency in AI or big data tools, employers predict that personal resilience, flexibility, and agility, along with leadership and social impact, will gain in importance (Di Battista et al., 2025, p. 41). Some participants and observers of reality go even further in their assessments, emphasizing what is most real in human existence, for example, the ability to rest, valuable sleep, and communication understood as the ability to build understanding with others (Jurga, 2025). Can AI tools support this? Certainly. But are tools themselves enough? No, because many competencies crucial for success, including the CEO's personal brand, depend on a thorough understanding of the socioeconomic space. Data and tools are valuable, but humans must make proper use of them.

The research results confirm previous findings on the role of the CEO's personal brand as a key resource affecting an organization's reputation (Cottan-Nir, 2019; Fetscherin, 2015; Górska, 2021). On one hand, AI simplifies content management and helps reach a broader audience. On the other hand, it raises concerns about potentially losing control over one's image. In extreme cases, this can lead to the complete dehumanization of the message, where a synthetic, algorithm-generated communication replaces the authentic voice of the leader. Moreover, AI introduces new ethical challenges related to transparency, authorship, and accountability for content generated by algorithms (Klenk, 2024). These issues are especially significant in the leadership context, where a leader's authenticity and credibility play crucial roles in shaping an organization's brand, fostering stakeholder relationships, and influencing the broader community (Haenlein et al., 2022; Uddin, 2023).

One of the main challenges highlighted by the interview results is finding a balance between efficiency and authenticity. Contemporary leaders operate in an environment where their personal brand serves as both a tool for creating organizational value and a means of social influence (Hambrick, Wowak, 2021; Olkkonen, Morsing, 2023). In this context, AI can be used to support image management, but its misuse can lead to a weakening of stakeholder trust and even a dehumanizing relationship between leaders and their audiences.

AI is likely to become an increasingly widely used tool. Every tool has its limitations and possible applications, and one of these is supporting the building of the CEO's personal brand. Like any tool used inappropriately, it can lead to very negative consequences.

6. Conclusions

This article contributes several important elements to the literature on the process of building a CEO's personal brand (Fetscherin, 2015; Scheidt et al., 2018; Cottan-Nir, 2019; Walczak-Skałecka, 2022), particularly with the use of AI-based tools. First, it is the initial attempt to systematize the opportunities, threats, and paradoxes associated with the use of AI tools in the process of building a CEO's brand, taking into account their perspective. Building a personal brand using AI tools is becoming increasingly common. AI is used both in the process of performing basic CEO tasks and in communication with the community. A CEO who wants to use AI tools while minimizing the associated risks must, in addition to technical competence, have high ethical standards and maintain transparency in their actions. Secondly, presented results highlight the importance of authenticity and credibility in establishing a CEO's personal brand, particularly in the digital environment. It complements the literature on communication ethics and image management in the era of generative technology (Ingenhoff, Sommer, 2010, Love et al., 2017, Górska, Mazurek, 2021, Klenk, 2024). Yet another insight is that authenticity remains a central and non-substitutable value in CEO personal branding, even when AI tools are involved. This confirms the assumptions of the conceptual funnel model of CEO brand equity (Cottan-Nir, 2019). While AI can enhance productivity, CEOs recognized the necessity of maintaining personal involvement, especially in activities requiring emotional engagement, empathy, and ethical responsibility. The respondents also stressed the importance of transparent authorship and data confidentiality, highlighting areas where ethical considerations should guide AI adoption.

From a practical perspective, CEOs should treat technology as a support, not as a substitute, in building their personal brands. Direct involvement in key communication remains essential. Leaders should stay engaged in content creation, ensure transparency, and define clear ethical rules for using AI tools. Organizations may introduce policies for employees that promote responsible and human-centered leadership communication. The results presented provide valuable guidance for practitioners to set standards and implement best practices for the ethical use of AI tools in building a CEO's personal brand.

The presented research results are significant for several reasons. First, they combine a new technological context with the well-established area of personal branding, while also incorporating the still insufficiently researched area of CEO personal branding. Second, they confirm the importance of trust and authenticity in CEO personal branding and leadership, thus complementing existing theories. Third, they provide guidance on key frameworks for setting ethical standards related to the use of AI tools in the personal branding process. Finally, they inspire further research, particularly in the area of observed changes in attitudes and real-world solutions tested in this area.

This study is not without limitations. First, the research is based on a small, non-representative sample of 12 CEOs. Future research should include larger and more diverse CEO populations, explore intersectional differences (e.g., gender, age, career stage), and examine differences in attitudes toward AI use in personal branding. Secondly, the research was interpretative in nature. The use of mixed-methods or longitudinal design to systematically measure changes in CEO attitudes over time to provide additional insights is recommended. Thirdly, the research was conducted in Poland. There could be cross-country differences in attitudes and perceptions toward the use of AI for building a personal brand. Therefore, additional studies conducted in other national contexts could enrich our understanding of the extrinsic and intrinsic factors that influence CEOs' adoption and use of AI in personal branding.

References

1. Afonso, K. (2025, January 23). The Ethical Considerations Of AI For C-Suite Executives. *Forbes*. https://www.forbes.com/councils/forbesbusinesscouncil/2025/01/23/the-ethical-considerations-of-ai-for-c-suite-executives/
2. Alvesson, M. (2003). Beyond neopositivists, romantics, and localists: A reflexive approach to interviews in organizational research. *Academy of Management Review, 28*(1), 13-33.
3. Barros, A., Rosenthal, B., Coelho, C., Leandro, B. (2025). 'Brazil must be a country for entrepreneurs and workers, not scoundrels': Personal branding mechanisms underpinning CEO activism. *Human Relations, 78*(1), 32-58. https://doi.org/10.1177/00187267241229036
4. Buck, B., Morrow, J. (2018). AI, performance management and engagement: keeping your best their best. *Strategic HR Review, 17*(5), 261-262. https://doi.org/10.1108/shr-10-2018-145
5. Citron, D.K., Chesney, R. (2019). Deepfakes and the New Disinformation War. *Foreign Affairs*. https://scholarship.law.bu.edu/shorter_works/76
6. Cottan-Nir, O. (2019). Toward a Conceptual Model for Determining CEO Brand Equity. *Corporate Reputation Review, 22*(4), 121-133. https://doi.org/10.1057/s41299-019-00063-3
7. Cottan-Nir, O., Lehman-Wilzig, S. (2018). CEO Branding: Between Theory and Practice — Case Studies of Israeli Corporate Founders. *International Journal of Strategic Communication, 12*(2), 87-106. https://doi.org/10.1080/1553118X.2018.1425691
8. Descartes, R. (1637). *Discours de la methode pour bien conduire sa raison, & chercher la verité dans les sciences: Plus la dioptrique, les meteores, et la geometrie, qui sont des essais de cete methode*.

9. Di Battista, A., Grayling, S., Játiva, X., Leopold, T., Li, R., Sharma, S., Zahidi, S. (2025). *Future of Jobs Report*. World Economic Forum. https://reports.weforum.org/docs/WEF_Future_of_Jobs_Report_2025.pdf
10. Doh, J.P., Quigley, N.R. (2014). Responsible leadership and stakeholder management: Influence pathways and organizational outcomes. *The Academy of Management Perspectives*, *28*(3), 255-274. https://doi.org/10.5465/amp.2014.0013
11. Evans, J.R. (2017). A strategic approach to self-branding. *Journal of Global Scholars of Marketing Science, 27*(4), 270-311. https://doi.org/10.1080/21639159.2017.1360146
12. Fetscherin, M. (Ed.) (2015). *CEO Branding. Theory and Practice*. Routledge.
13. Freeman, R.E. (2010). *Strategic management: A stakeholder approach*. Cambridge University Press.
14. Gander, M. (2014). Managing your personal brand. *Perspectives: Policy and Practice in Higher Education, 18*(3), 99-102. https://doi.org/10.1080/13603108.2014.913538
15. Ghorashi, S.Y., Kheiri, B., Amirshahi, M. (2019). Investigation into the Effective Factors Involved in Personal Brand Equity of University Professors. *Iranian Journal of Educational Sociology, 2*(4), 166-178. https://doi.org/10.29252/ijes.2.4.166
16. Glinka, B., Czakon, W. (2021). *Podstawy badań jakościowych*. PWE.
17. Gorbatov, S., Khapova, S.N., Lysova, E.I. (2018). Personal Branding: Interdisciplinary Systematic Review and Research Agenda. *Frontiers in Psychology, 9*(2238), 1-17. https://doi.org/10.3389/fpsyg.2018.02238
18. Górska, A. (2021). The True or the Idealized Self: How CEOs Build Their Personal Brands? *Central European Management Journal, 29*(1), 39-60. https://www.ceeol.com/search/article-detail?id=966255
19. Górska, A., Mazurek, G. (2021). The effect of the CEO media coverage on corporate brand equity: Evidence from Poland. *Oeconomia Copernicana, 12*(2), 499-523. https://doi.org/10.24136/oc.2021.017
20. Grabmeier, S. (2020, July 28). *BANI versus VUCA: a new acronym to describe the world*. https://stephangrabmeier.de/bani-versus-vuca/
21. Grewal, D., Hulland, J., Kopalle, P.K., Karahanna, E. (2020). The future of technology and marketing: a multidisciplinary perspective. *Journal of the Academy of Marketing Science, 48*(1), 1-8. https://doi.org/10.1007/s11747-019-00711-4
22. Grzeszkiewicz-Radulska, K. (2012). Metody badań pilotażowych. *Acta Universitatis Lodziensis Folia Sociologica, 42*, 113-141.
23. Haenlein, M., Huang, M.-H., Kaplan, A. (2022). Guest editorial: Business ethics in the era of artificial intelligence. *Journal of Business Ethics, 178*(4), 867-869. https://doi.org/10.1007/s10551-022-05060-x
24. Hambrick, D.C., Wowak, A.J. (2021). CEO sociopolitical activism: A stakeholder alignment model. *The Academy of Management Review, 46*(1), 33-59. https://doi.org/10.5465/amr.2018.0084

25. Harvey, P., Martinko, M.J., Gardner, W.L. (2006). Promoting Authentic Behavior in Organizations: An Attributional Perspective. *Journal of Leadership & Organizational Studies, 12*(3), 1-11.
26. Hearn, A. (2008). 'Meat, Mask, Burden': Probing the contours of the branded 'self'. *Journal of Consumer Culture, 8*(2), 197-217. https://doi.org/10.1177/1469540508090086
27. Ingenhoff, D., Sommer, K. (2010). Trust in Companies and in CEOs: A Comparative Study of the Main Influences. *Journal of Business Ethics, 95*(3), 339-355. https://doi.org/10.1007/s10551-010-0363-y
28. Jurga, J. (2025, January 15). *Kompetencje przyszłości.* https://www.linkedin.com/posts/joanna-jo-jurga-phd-6014588b_moje-sm-wybuch%C5%82y-informacjami-o-nowym-raporcie-activity-7284459158915997696-Og-y?utm_source=share&utm_medium=member_desktop&rcm=ACoAAAB4vqEBN0pHJ5Yw99MmyfNeZOIPJYIPq4Q
29. Klenk, M. (2024). Ethics of generative AI and manipulation: a design-oriented research agenda. *Ethics and Information Technology, 26*(1), 1-15. https://doi.org/10.1007/s10676-024-09745-x
30. Kowalczyk, E. (2020). Nowe wyzwania dla zarządzania karierą opartego na marce osobistej pracownika. In: J. Cewińska, A. Krejner-Nowecka, S. Winch (Eds.), *Zarządzanie kapitałem ludzkim: Wyzwania* (pp. 231-247). Oficyna Wydawnicza SGH.
31. Kucharska, W. (2017). Consumer social network brand identification and personal branding. How do social network users choose among brand sites? *Cogent Business & Management, 4*(1), 1315879. https://doi.org/10.1080/23311975.2017.1315879
32. Lair, D. J., Sullivan, K., Cheney, G. (2005). Marketization and the Recasting of the Professional Self: The Rhetoric and Ethics of Personal Branding. *Management Communication Quarterly, 18*(3), 307-343. https://doi.org/10.1177/0893318904270744
33. Le Roux, T., Lucinda, B.S. (2022). From a VUCA to a BANI world: Has the view and practice of internal communication changed through the pandemic? In: D. Verčič, A. Tkalac Verčič, K. Sriramesh (Eds.), *Reboot: Should Organizations Rediscover Communication with Internal & External Stakeholders?* (pp. 86-88). University of Ljubljana.
34. Love, E.G., Lim, J., Bednar, M.K. (2017). The Face of the Firm: The Influence of CEOs on Corporate Reputation. *Academy of Management Journal, 60*(4), 1462-1481. https://doi.org/10.5465/amj.2014.0862
35. Macalik, J. (2023). Personal Brand—Instructions of Use. Do Young Professionals Want and Need to be Taught Personal Branding? *Marketing of Scientific and Research Organizations, 48*(2), 41-60. https://doi.org/10.2478/minib-2023-0009
36. Mantulenko, V.V., Yashina, E.Z., Ashmarina, S.I. (2020). Personal Brand of University Teachers in the Digital Age. In: S.I. Ashmarina, M. Vochozka, V. V. Mantulenko (Eds.), *Digital Age: Chances, Challenges and Future, Vol. 84* (pp. 62-70). Springer International Publishing. https://doi.org/10.1007/978-3-030-27015-5_8

37. Muszyńska, W. (2022). Postrzeganie i wykorzystanie marki osobistej w pracy zawodowej przez przedstawicieli wybranych zawodów prawniczych [Perception and use of a personal brand in professional work by representatives of selected legal professions]. *The Scientific Journal of the Polish Economic Society, 9*(17), 19-31. https://doi.org/10.26366/PTE.ZG.2022.222
38. Olkkonen, L., Morsing, M. (2023). A Processual Model of CEO Activism: Activities, Frames, and Phases. *Business & Society, 62*(3), 646-694. https://doi.org/10.1177/00076503221110184
39. Omojola, O. (2008). Audience Mindset and Influence on Personal Political Branding. *Journal of Social Sciences, 16*(2), 127-134. https://doi.org/10.1080/09718923.2008.11892609
40. Parmentier, M.-A., Fischer, E. (2012). How athletes build their brands. *International Journal of Sport Management and Marketing, 11*(1/2), 106. https://doi.org/10.1504/IJSMM.2012.045491
41. Peters, T. (1997). The brand called You. *Fast Company, August/September*. https://www.fastcompany.com/28905/brand-called-you
42. Przegalinska, A., Jemielniak, D. (2023). *Strategizing AI in business and education: Emerging technologies and business strategy.* Cambridge University Press. https://doi.org/10.1017/9781009243520
43. Scheidt, S., Gelhard, C., Strotzer, J., Henseler, J. (2018). In for a penny, in for a pound? Exploring mutual endorsement effects between celebrity CEOs and corporate brands. *Journal of Product & Brand Management, 27*(2), 203-220. https://doi.org/10.1108/JPBM-07-2016-1265
44. Staniszewska, Z., Górska, A. (2021). Marka osobista CEO: różnice w sposobach kreacji wśród kobiet i mężczyzn. *Kobieta i Biznes, 1-4, 2-55*.
45. Turing, A.M. (1950). Computing Machinery and Intelligence. *Mind, 49*, 433-460.
46. Uddin, A.S.M.A. (2023). The era of AI: Upholding ethical leadership. *Open Journal of Leadership, 12*(04), 400-417. https://doi.org/10.4236/ojl.2023.124019
47. Vallas, S.P., Christin, A. (2018). Work and Identity in an Era of Precarious Employment: How Workers Respond to "Personal Branding" Discourse. *Work and Occupations*, *45*(1), 3-37. https://doi.org/10.1177/0730888417735662
48. Venciute, D., April Yue, C., Thelen, P.D. (2024). Leaders' personal branding and communication on professional social media platforms: motivations, processes, and outcomes. *Journal of Brand Management*, *31*(1), 38-57. https://doi.org/10.1057/s41262-023-00332-x
49. Walczak-Skałecka, A. (2022). *Koncepcja marki osobistej w świetle wybranych teorii tożsamości narracyjnej*. Rozprawa doktorska. Uniwersytet Marii Curie-Skłodowskiej. http://bc.umcs.pl/dlibra/publication/49858/edition/46152/content

50. Wijaya, B.S., Amir, M.T., Lucyanda, J. (2021). Why Do Educational People Commit Corruption in Communicating Their Personal Brands? *Proceedings of the International Conference on Educational Sciences and Teacher Profession (ICETeP 2020)*, 85-90. https://doi.org/10.2991/assehr.k.210227.014
51. Wowak, A.J., Busenbark, J.R., Hambrick, D.C. (2022). How do employees react when their CEO speaks out? Intra- and extra-firm implications of CEO sociopolitical activism. *Administrative Science Quarterly*, *67*(2), 553-593. https://doi.org/10.1177/00018392221078584

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ASSESSING THE USEFULNESS OF SIMPLIFIED PROJECT MANAGEMENT FRAMEWORKS IN A SMALL ENTERPRISE CONTEXT

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Purpose: The study aims to evaluate the applicability and perceived usefulness of a light-weight project management methodology tailored for small-scale projects, particularly within environments with limited project management experience and resources.
Design/methodology/approach: An experimental research design involving multiple student-led teams executing real-world small projects over four months was employed. The methodology under evaluation was systematically applied by each team, supported by trained mentors. Data were collected through structured surveys assessing various dimensions of the methodology's practicality and effectiveness, including documentation, role clarity, stakeholder engagement, and risk management.
Findings: The findings indicate that simplified project management approaches can effectively support small project environments. Respondents reported high satisfaction levels with the ease of use, clarity of documentation, and effectiveness of core tools such as role assignment mechanisms, project boards, and deliverables mapping. The methodology also demonstrated utility in enhancing stakeholder communication and managing evolving project requirements. Minor challenges were observed, primarily related to stakeholder engagement variance and unforeseen risks.
Research limitations/implications: The study's limitations include student teams in an academic setting, not fully reflecting commercial pressures or dynamics. Mentor involvement may have inflated performance, limiting findings' generalizability and needing further research.
Practical implications: The study suggests that small enterprises and nonprofit organisations can benefit from adopting streamlined methods that emphasise clarity, frequent feedback, and simple documentation.
Originality/value: This study contributes to the limited empirical literature on project management in small-scale and resource-constrained environments. It provides evidence-based insights into minimalist project management methodologies' practical benefits and limitations, offering value for researchers, practitioners, and educators seeking adaptive, accessible tools for managing small projects in SMEs, NGOs, and student settings.
Keywords: small projects, project management methodology, experimental research, stake-holder engagement, lightweight frameworks, SMEs.
Category of the paper: Research paper. The testing of a framework.

1. Introduction

While substantial research has focused on project management practices for large and complex projects, much less attention has been given to the challenges small and medium-sized enterprises (SMEs) face in managing small-scale initiatives (Bai et al., 2016). Traditional methodologies, such as PMBOK or PRINCE2, are often too resource-intensive and require high levels of expertise, making them unsuitable for micro-project environments where simplicity, adaptability, and limited overhead are critical. This misalignment is particularly problematic given that SMEs account for a significant share of employment and innovation in both developed and emerging economies (Turner et al., 2012; Marcelino-Sádaba et al., 2014). In the European Union alone, they generate 66.7% of employment, employing over 90 million people (Marcelino-Sádaba et al., 2014). Studies show that projects can be associated with more than 40% of the turnover of small and medium-sized projects (Turner et al., 2012). SMEs require project management to effectively manage their innovation, achieve growth, and meet strategic goals while minimising high inherent risks. However, these companies lack project monitoring and control systems, have poorly distributed roles and management structures, and lack experienced project managers (Turner et al., 2009). This situation has evolved in recent years due to the increasing popularity of project management methodologies, but other barriers still prevent a comprehensive solution to this problem.

Small organisations often lack the expertise or resources necessary to participate in the creation of standards (Laporte, Chevalier, 2015). None of the existing waterfall or agile methodologies are fully adapted to the needs of small companies and small projects (Kolimar et al., 2022). The tailoring proposed by the authors of these methodologies does not work in practice due to the lack of advanced project competences (Marcelino-Sádaba et al., 2014). Rigid adherence to predefined methodologies that are not tailored to the organisation's and projects' specific needs leads to delays, errors, and budget overruns. Therefore, it is necessary to propose methodologies specifically designed for small projects. In recent years, such methodologies have been emerging. One example is micro.P3.express. Unfortunately, unlike large and well-known methodologies, no studies show their usefulness in project management.

Existing literature acknowledges the need for lightweight or minimalist project management approaches tailored to the unique constraints of SMEs (Rowe, 2020; Zaheri et al., 2022). However, there is a lack of empirical studies that evaluate these approaches under controlled, yet practical, conditions (Rode et al., 2024). Prior research tends to be conceptual or based on single case studies, offering limited generalizability. This study addresses that gap by experimentally assessing a simplified project management methodology designed for micro-projects, focusing on its ease of use, stakeholder engagement, and support for planning and control in resource-constrained contexts.

The study aimed to assess the usefulness of the micro.P3.express methodology and the tools it uses for managing small projects. The following research questions were formulated in the study:

- Is the studied methodology easy to use in teams without project experience?
- Do the techniques proposed by the methodology (roles, project board, follow-up register, deliverables map) support project implementation?
- Does the methodology properly and sufficiently support stakeholder relationship management?
- Does the methodology properly and sufficiently support requirements management?

The article is organised as follows: the next section presents a literature review, confirming the problems associated with managing small projects. The research methodology is then discussed, followed by presenting research results, discussion, and conclusions.

2. Literature review

2.1. Project management in Small and Medium-Sized Enterprises

Small and medium-sized enterprises (SMEs) make key contributions to the economy in terms of employment, innovation, and growth. Project management can significantly facilitate this contribution, but SMEs require less bureaucratic project management than larger, well-structured organisations (Turner et al., 2010). SMEs more often implement projects to achieve outcomes related to direct market activities. They are characterised by a more significant efficiency orientation, with a dominant intention to increase revenues, while large enterprises prefer economic options related to optimisation and reduction of operating costs (Kozlowski, Matejun, 2016). Micro, small and medium-sized enterprises spend about the same percentage of turnover on projects, but the smaller the company, the smaller the projects it implements and the less often it uses project management and its tools. Projects implemented in small companies are short. Most of them are in the range of 3-12 months (Turner et al., 2009). At the same time, these projects are more prone to risk due to their inherent characteristics, such as resource constraints, tight schedules, competition and low-profit margins. This causes limited formal documentation. The main problem becomes the disproportion between management expenditure and project costs (Hwang et al., 2014).

Many of these projects occur in parallel with the company's current operations (Marcelino-Sádaba et al., 2014). Small companies rarely have dedicated project managers and are less likely to adopt project management practices (Turner et al., 2012). It is typical for SMEs to have employees participating in multiple projects simultaneously, acting as participant or manager while performing current tasks resulting from their job position. This forces frequent switching

between tasks and reduces the quality of work (Rowe, 2020). In some organisations, there are no employees who are not involved in at least one project. At the same time, some companies consciously undertake more projects than they can complete to maximise the use of their resources (Bai et al., 2016). Therefore, people without management training who attend small projects need simple methods and techniques to implement them (Laporte, Chevalier, 2015) effectively.

Concerning the processes and tools used for project management, small and medium-sized enterprises are noticing a tendency to use less formal approaches, simplify planning and control techniques, and limit formal reporting. SMEs do not use all project management tools, such as PERT or milestone planning, as confirmed by research indicating their limited presence in these enterprises (Sane, 2020). Standardisation is low, and decision-making is based mainly on intuition (Kozlowski, Matejun, 2016; Turner et al., 2012). The abandonment of tools is not only due to haste or reluctance. Some techniques are not readily adaptable to small projects. Many processes from large organisations do not scale well to small ones (Rowe, 2020). For example, the essential IT tool, Microsoft Project, is treated by project managers from small organisations as too complicated for their needs (Turner et al., 2010).

Projects in SMEs are often run by company owners, who usually do not have formal management education (Zaheri et al., 2022). Owners influence project management to control the development of the whole organisation (Turner et al., 2010). Project management in small companies is often carried out by one person, without the support of specialists from inside and cooperation with the business partners. Not having their own technological solutions, small companies are more willing than large ones to use advanced communication technologies and highly specialised equipment (Kozlowski and Matejun, 2016). At the same time, the use of advanced project management tools (CPM, EVM) remains low (Turner et al., 2009).

Small and medium-sized enterprises expect that project management methodologies, methods and techniques will be adapted to the specifics of small projects (Zaheri et al., 2022). They require simple planning, control and reporting tools. They often do not need standardisation, which is required by companies with many large projects (Turner et al., 2010). Project methodologies intended for large projects cannot be straightforward adaptations, but they should be prepared from scratch with small projects in mind (Rowe, 2020). Tailoring does not work because its application requires high project management competencies, which are unavailable in SMEs. SMEs do not see an economic justification for using ISO standards or project management methodologies. Given the scale of their operations, they treat them as a source of costs that do not bring benefits (Laporte, Chevalier, 2015). In small projects, much more depends on people's attitudes. SMEs expect methodologies that focus on the involvement of project team members, efficient work and resource management rather than creating documentation (Turner et al., 2012).

2.2. Limitations of existing project management methodologies

Most of the available waterfall methodologies and some agile ones were designed primarily for managing large or medium-sized projects (Jovanovic, Bric, 2018; Piwowar-Sulej, 2021). They are not suitable for solving the problems faced by small enterprises (Marcelino-Sádaba et al., 2014). The main weaknesses of standards in the context of their application in SMEs include insufficient guidance on the selection and application of standards, difficulty in understanding standards, the cost of acquiring and implementing standards, the cost of certification, and the slow evolution of standards, which may inhibit innovation (Laporte, Chevalier, 2015). SMEs have limited time and financial resources, leading to a lack of understanding of how to use standards to their advantage. Standards such as ISO describe what should be done but do not explain how it should be done, making practical implementation difficult. Some B2B customers expect the use of several different standards and methodologies, which leads to conflicts between their requirements. Meanwhile, managers of small projects rarely have sufficient competencies to resolve these conflicts. Companies in the SME sector often do not gain clear benefits from the implementation of the standards. The cost of training, implementation and certification is also significant. Standards introduce additional bureaucracy, which requires additional employees and increases operating costs without leading to increased revenues (Laporte, Chevalier, 2015).

Turner et al. (2010) point out that waterfall methodologies, in particular, do not meet the needs of SMEs in terms of flexibility and formalisation. The formal decision-making process is irrelevant when the only decision-maker is the company's owner. Defined structures do not work correctly when each employee participates in several projects simultaneously, sometimes as a manager and sometimes as a team member. The waterfall approach requires a significant dose of planning at the beginning of the project, which may be cost-ineffective in the case of small projects and is also unwelcome to the clients, who do not yet know all of their requirements. Changes during project implementation are frequent, which leads to tensions between the project team and the client (Kolimar et al., 2022). PMBOK supporters emphasise that tailoring allows for the selection of processes, techniques, and approaches appropriate for a given project. Unfortunately, tailoring requires good knowledge of the standard and extensive experience from the project manager. A person without a management education cannot choose the right tools and processes from a document seen for the first time, which is several hundred pages long (Zaheri et al., 2022). The PMBOK approach has changed with the 7th edition and is now easier to adapt to small projects. However, it still requires too many competencies (Maslennikov et al., 2022). PRINCE2 is less flexible than PMBOK. It works well in large and structured projects, but the formalisation of this methodology significantly limits the flexibility necessary in projects implemented by SMEs. Other weaknesses for small projects are high competency requirements and a broad scope of project documentation (Hasibovic, Tanovic, 2019).

The studies show that agile methodologies do not fully meet the needs of SMEs and minor projects, too. Agile methodologies strongly rely on the team's competencies and the client's commitment and understanding of the approach. In practice, SME clients are usually unfamiliar with agile project management, which leads to misunderstandings. Clients expect the project team to take full responsibility despite the limited project planning phase. The continuous introduction of changes typical of agile projects is more demanding for the team, especially when its members participate in several projects simultaneously (Kolimar et al., 2022). This is especially visible in Scrum, where incomplete stakeholder involvement can easily lead to project failure. The decision to change the waterfall approach to Scrum in SMEs only to increase flexibility often does not lead to the intended effects. In turn, the lack of documentation, although convenient for the team, is a source of problems in contact with the client (Hasibovic Tanovic, 2019). Extreme Programming is associated with techniques and procedures that can be burdensome for small companies without developed IT support. Therefore, practices such as on-site customer, continuous testing and integration can be an obstacle to completing small projects. Using agile methodologies in small projects with relatively constant requirements leads to problems meeting the schedule (Anwer et al., 2017).

2.3. The need for lightweight, fit-for-purpose methodologies

Researchers have advocated lightweight or minimalist methodologies – simplified frameworks explicitly designed for small projects and teams. Turner et al. (2010) proposed developing a light version of project management methodologies. Authors stated that small companies will need an even more straightforward method called micro-lite (Turner et al., 2012). This methodology should focus on the definition of people and requirements. It should use simplified scheduling, risk management, cost management and reporting techniques. Anwer et al. (2017) proposed Tailored Extreme Programming as a response to the limitations resulting from the XP methodology. Kozlowski and Matejun (2016) proposed a hybrid project management model adapted to the specifics of SMEs. Kolimar et al. (2022) developed the assumptions of the methodology, which in the first phase retains the planning elements typical of the waterfall approach but later uses an iterative approach. Rowe (2020) proposed focusing project management on four issues: planning, situation analysis, task delivery, and monitoring, but in a way that is formalised at a minimal level. A similar proposal was made by Zaheri et al. (2022), who compared this simplified approach to the use of tailored processes proposed by PMBOK and obtained better results. Hasibovic and Tanovic (2019) suggest combining the strengths of PRINCE2 and Scrum to develop a flexible but easy-to-use methodology. Another interesting direction is using ISO 29110 standards, which are dedicated to managing software projects in small organisations (Laporte, Chevalier, 2015). However, this standard remains unclear concerning the compatibility with ISO 21500 family of standards and other management standards, which require further work.

These methods emphasize core project functions (e.g., planning, stakeholder coordination, deliverable tracking) while reducing bureaucratic load. However, empirical validation of such frameworks is lacking. Most existing literature is conceptual, case-based, or anecdotal, with few experimental or comparative evaluations (Kolimar et al., 2022). This creates a pressing gap for research that tests whether simplified methodologies actually meet the operational needs of small teams and resource-constrained environments.

2.4. Micro.P3.Express methodology

The micro.p3.express methodology is a minimalist project management system designed specifically for micro-projects, which usually involve small teams (mi-cro.P3.express, 2022). It is a simplified version of the P3.express framework, which aims to provide an effective and simple approach to managing small projects in a variety of environments (Rad, Turley, 2021). The system is scalable and versatile, allowing it to be used by freelancers, small teams, and individuals alike. This is particularly important in the dynamic landscape of project management, where traditional methods such as PRINCE2 or PMBOK Guide can be too complicated for smaller projects.

The methodology is based on the following principles. The micro.P3.express system is designed for small teams of 1-7 people, making it ideal for micro-projects. The system is characterized by minimalism and simplicity, avoiding excessive documentation and focusing on key activities such as planning, risk monitoring and problem solving. Furthermore, the basis for successful project management with this methodology is adherence to the Nearly Universal Principles of Projects (NUPP), which form the foundation for effective management. It is based on a process structure divided into six groups of activities, including two one-time activities and four cyclical activities (micro.P3.express, 2022). Figure 1 shows the project management process of micro.P3.express.

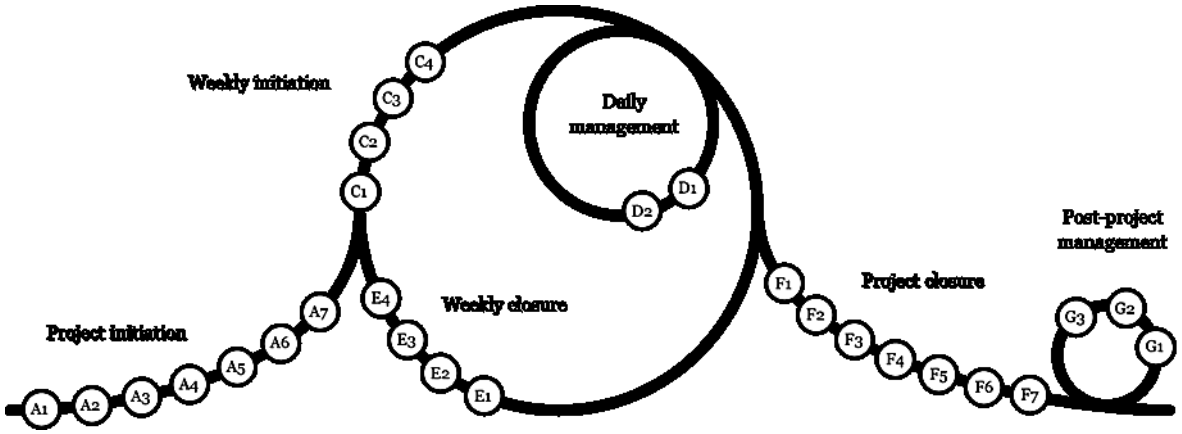

Figure 1. Structure of the micro.P3.express process.

Source: (micro.P3.express, 2022).

The activity groups in the micro.P3.express methodology include (Rad, Turley, 2021):

- Project initiation (linear group of activities, one-time) – consists of preparing the project for implementation, i.e. identifying a sponsor, dividing roles in the team, developing project documentation, planning and making decisions about the project implementation.
- Weekly initiation (cyclical group of activities) – consists of checking the business justification, reviewing tasks and preparing for a new project cycle.
- Daily management (cyclical group of activities) – consists of ongoing management of project products and derived elements (risks, problems, changes, improvements, experiences).
- Weekly closure (cyclical group of activities) – consists of analysing the project results achieved in the last cycle, assessing stakeholder satisfaction and planning improvements.
- Project closure (linear group of activities, one-time) – consists of reviewing project results, transferring products to end users and archiving documentation.
- Post-project management (cyclical group of activities) – consists of evaluating the benefits of a project and generating new ideas.

Additionally, the flexibility allows for the adaptation of work cycles; for longer projects that do not require intensive involvement, the weekly cycle can be changed to a monthly one, allowing for a better fit to the specifics of the project.

3. Methodology

This study employed an exploratory, quasi-experimental research design to evaluate the practical utility of a lightweight project management methodology in small-project settings. Experiments are rarely used in project management studies due to the difficulty of conducting, obtaining data, and above all, designing in a way that can be repeated. Very short experiments conducted in strictly controlled conditions dominate, which makes it difficult to draw broader conclusions (Kutsch et al., 2011). Studying the application of project management methodology with the help of an experiment allows for collecting observations regarding actual usefulness in diverse environmental conditions. The results can be used to improve the tested and other project methodologies.

As part of the experiment, teams composed of students were planned under the supervision of mentors, and small projects were implemented in practice. The preparation and implementation time of the project did not exceed 4 months. During the implementation, the teams were supported by mentors. The task of mentors with experience in project management was to help the early identification of risk factors and to respond in the event of

problems exceeding the capabilities of the teams. Such a procedure was necessary because, in most cases, the teams had no project experience. In practice, such problems did not occur during the experiment.

The project topics and the place of their implementation were selected by the teams. The projects were implemented mainly in small and medium-sized enterprises and student organisations. The teams consisted of 3-5 people. The teams were created based on the preferences of their members without the participation of mentors. In about half of the cases, the students had known each other for at least half a year before the team was created. The fact of prior acquaintance had no significant significance for the results presented below.

The procedure followed the micro.P3.express methodology and included the following main steps:

- Initiation and planning phase (familiarising students with the micro.P3.express methodology, creating project teams, selecting the project topic and agreeing with stakeholders, developing project documentation, approving the project documentation by the mentor and stakeholders).
- Implementation phase (weekly update of plans, implementation of tasks by teams, assessment of the degree of project implementation, documentation update, regular communication with the mentor and stakeholders.
- Closing phase (delivery of project results, obtaining approval from stakeholders, presentation of a project report).

In the case of some projects, the results were also provided during the implementation phase (e.g., organising a series of workshops for students). The project report presented the degree to which the goals and requirements were met and the results were delivered.

After completing and assessing the projects, each group of students received a survey in which they could evaluate the usefulness of the micro.P3.express methodology for use in small projects. The survey was prepared in accordance with the formulated research questions and consisted of the following sections: general evaluation, roles management evaluation, project board evaluation, follow-up register evaluation, deliverables map evaluation, stakeholder management, requirements management. Cronbach's Alpha was 0.76, which is interpreted as a good result. The result would have been much higher if not for the use of control questions, to which the answer was expected to be the opposite of most answers. Such a procedure negatively affects the Cronbach Alpha value, but at the same time increases the credibility of the obtained answers.

Data was collected through an online questionnaire survey in January and February 2025. To maintain data quality and validity, various verification measures were implemented, including assessing the completeness of questionnaires, comparing the time taken to fill out each form against the average completion time, and scanning for any patterns or inconsistencies in the responses. Control questions were introduced to identify filling in the questionnaire without reading. This rigorous data collection procedure ensured that the findings derived from

the study were both reliable and indicative of the true views and opinions of respondents within the target population.

The study investigating the application of the micro.P3.express methodology in student-led projects was conducted strictly according to ethical principles to ensure participants' integrity, independence, and respect. The following measures were implemented to address key ethical considerations. To maintain impartiality, the evaluation of the micro.P3.express methodology was separated from the academic assessment of the students' projects. Students were explicitly informed that participation in the survey was unrelated to their project grades or educational outcomes, ensuring their responses were provided freely and without external pressure. Before participating in the survey, all students were provided with comprehensive information about the study's objectives, the scope of data collection, and the intended use of the results. The form also outlined participants' rights, including anonymity and data protection. The survey was designed to ensure complete anonymity of respondents. No personally identifiable information was collected, such as names, student IDs, or project details. Data were gathered using a secure online platform that was compliant with GDPR standards for data protection. Participants were informed about the data storage and processing procedures, and it was emphasised that results would only be reported in aggregated form, preventing any possibility of linking responses to individual students. Data quality was maintained through rigorous verification processes, including checks for questionnaire completeness, response time analysis, and screening for inconsistent patterns. These ethical measures were implemented to uphold the highest standards of research conduct, safeguard participant rights, and ensure the study's findings were robust and trustworthy.

4. Results

The projects on which the application of the micro.P3.express methodology was evaluated were diverse (Figure 2). The most common projects involved promotional campaigns (27%), educational events (21%), and charity events (21%). Other projects consisted of organising social events (10%), developing e-learning courses (9%), and developing educational campaigns (9%). The projects surveyed included two that involved creating a podcast and one that involved renovating a medical facility.

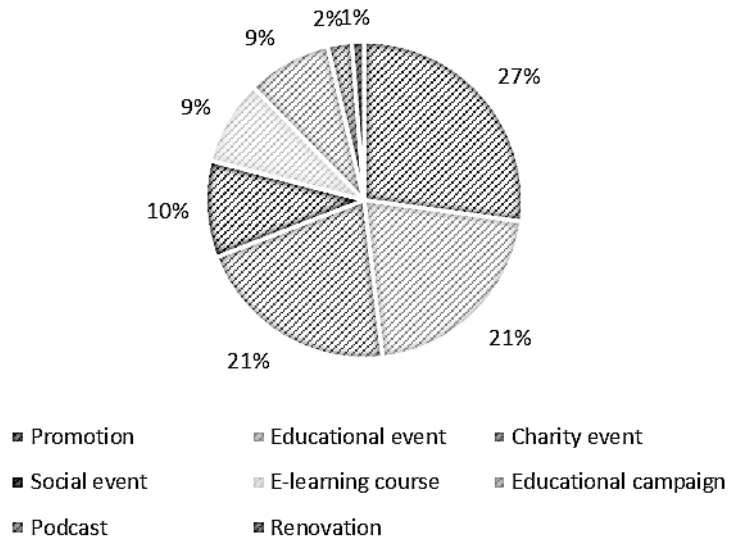

Figure 2. Types of projects.

Source: research results.

The micro.P3.express methodology was evaluated based on an analysis of several key aspects to understand how its application affects project implementation. Respondents were asked to rate each process element on a seven-point scale (1-7, disagree-agree), allowing detailed analysis of their experiences and opinions. The main areas included the ease of preparing the documentation, its completeness and usefulness during project implementation, as well as the effectiveness of the methodology itself in facilitating management and potential problems arising from its limitations. Figure 3 presents the study's results regarding the overall assessment of the approach.

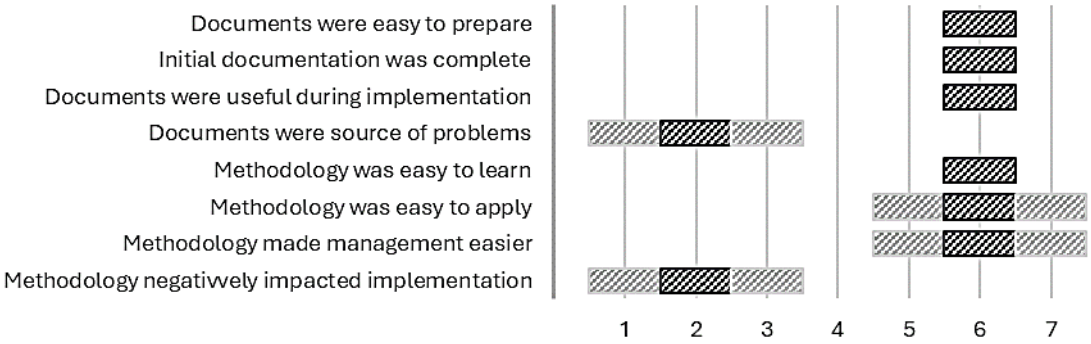

Figure 3. General evaluation of the approach.

Source: research results.

Respondents felt that the project documentation was easy to prepare. Similarly, the majority thought that the documentation prepared at the beginning of the project contained all the necessary information. The documentation was rated as very useful during project implementation. In these aspects, the median response equals 6, and the average absolute deviation is 0. The lack of scatter indicates complete agreement in the perception of these characteristics, and the responses obtained confirm the practical value of the approach used.

At the same time, the way the documentation was developed rarely caused problems, as indicated by the lower median equal to 2. In this case, the average absolute deviation is 1, which means that there was some variation in opinion. Respondents also agreed that the methodology basics were easy to learn and apply in practice, as evidenced by a median of 6. However, when evaluating the ease of application, respondents were less in agreement than when evaluating the ease of learning the basics of the methodology. In addition, the methodology made the project easier to manage, as confirmed by a median of 6, and the limitations of the methodology rarely negatively affected project implementation, as evidenced by lower ratings (median of 2). A slight variation in responses can also be seen in these questions, as the average absolute deviation was 1. The overall picture indicates user satisfaction and belief in the benefits of implementing the micro.P3.express methodology in projects.

The results of the evaluation of the hat method are shown in Figure 4. In most of the cases analysed, the teams used a hat (role) division in accordance with the micro.P3.express methodology, as evidenced by a median response of 6. Hat assignment was generally performed well as a method of role division (median equal to 5), and team members exchanged hats somewhat regularly (median equal to 5). In each of the three criteria, the mean absolute deviation equals 1, which may suggest a slight ambiguity or subjective differences in perceptions of particular aspects.

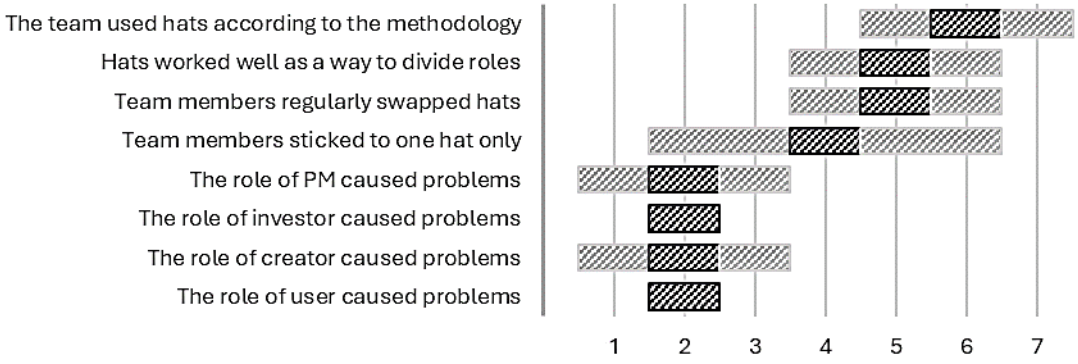

Figure 4. Hats (roles) evaluation.

Source: research results.

A median of 4 indicates that the overall evaluation bias oscillates around a neutral value – respondents do not explicitly express strong agreement or disagreement with the thesis that a rigid division of roles is a better solution. However, the mean absolute deviation of 2 suggests that there were quite significant differences in ratings among participants.

A low median of 2 indicates that respondents were unlikely to experience problems with the roles of project manager, developer, creator or user. There was relatively little difference in respondents' opinions regarding issues with the roles of project manager and developer, as indicated by a mean absolute deviation of 1.

The results of the project board evaluation are shown in Figure 5. Regarding time management, respondents rated the issues of using the project board and organising project team meetings. Most respondents rated the project board as an intuitive and easy-to-use tool, as evidenced by a median of 6. On this issue, a consensus was observed among respondents on the evaluation of the project board, as evidenced by a mean absolute deviation of 0.

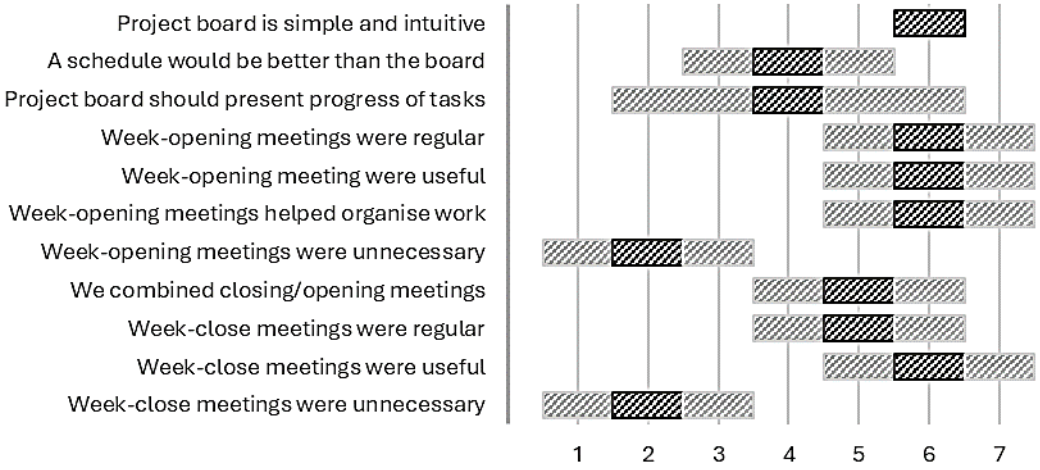

Figure 5. Project board evaluation.

Source: research results.

Respondents were neutral in their assessment of whether the development of a schedule would be preferable to a project board, and whether this one should have a layout according to the advancement of activities. On both issues, the median response was 4. Despite the slight variation in responses on the schedule issue, respondents were more in agreement than on the layout of the project board, as here the average absolute deviation was 2.

All opinions about the week's opening meetings (except for the question about annoyance) have a high median of 6, indicating that in most cases they were conducted regularly, respondents find them valuable and orderly for the teams. The mean absolute deviation of 1 suggests that most responses cluster near the median. The question about annoyance has a low median (2), confirming that respondents do not see these meetings as unnecessary. The mean absolute deviation in opinions on opening meetings equals 1, indicating relatively slight variation in respondents' answers.

A median equal to 5 indicates a relatively positive tendency to combine meetings. The mean absolute deviation of 1 suggests that respondents' opinions are mostly consistent, although some attitudes toward this solution vary.

It can be read from the results that closing meetings were primarily conducted somewhat regularly, as indicated by a median equal to 5. In addition, the usefulness of closing meetings was rated highly (median equal to 6). A median equal to 2 confirms that respondents generally did not consider closing meetings of the week to be an unnecessary nuisance. As in the case of opening meetings, the mean absolute deviation equal to 1 in opinions regarding closing meetings reports relatively slight variation in respondents' answers.

Figure 6. Follow-up register evaluation.

Source: research results.

Figure 6 refers to the evaluation of the registry of derivative elements. Overall, the management of derivative elements was rated positively by respondents. The distribution of responses shows that, for the most part, project teams identified the risk factor prior to commencement and that the derivative element register was updated at weekly meetings - a noticeably high percentage of ratings in the higher value sector (e.g., 5 and 6) with a median of 5 in both questions. The results also show that the majority made immediate updates to the element registry (median equal to 6) and that the derived element registry facilitated event management (median equal to 6). The same median (6) confirms the positive assessment of the use of the registry in the context of preparing for risks, and that despite the use of the derivative element registry, teams encountered unforeseen risk factors in the projects analysed. In all responses regarding the management of derivative elements, the mean absolute deviation of 1, despite the slight variation, suggests general agreement among respondents on the issues presented.

Figure 7 shows the results of the evaluation of the results map. The high rating of respondents (median equal to 6) and their agreement (mean absolute deviation equal to 0) confirm that in the projects analysed, the results matrix included direct products of the projects.

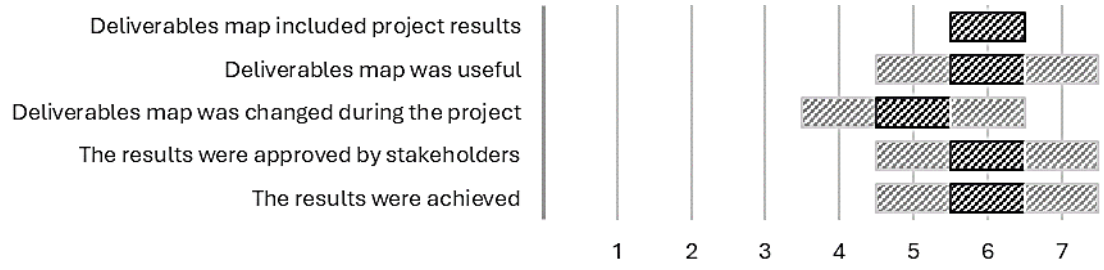

Figure 7. Deliverables map evaluation.

Source: research results.

In addition, respondents mostly agreed that the results matrix was helpful in defining the backlog (median equal to 6). A median equal to 5 indicates that respondents generally agreed with the statement that the results structure changed during the project. This means that most participants noticed some modification in the structure of the results - this was not extreme, but relatively moderate. The majority of responses at levels 6 and 7 confirm that the main results

of the projects were approved by the stakeholders and that the detailed results were achieved (median equal to 6). The average absolute deviation equal to 1 in the cases described indicates relatively consistent opinions of respondents.

The results of the survey regarding stakeholder management are shown in Figure 8. Most respondents (median equal to 6) declared that stakeholder analysis was conducted diligently before the project, and preferred communication channels were established with them.

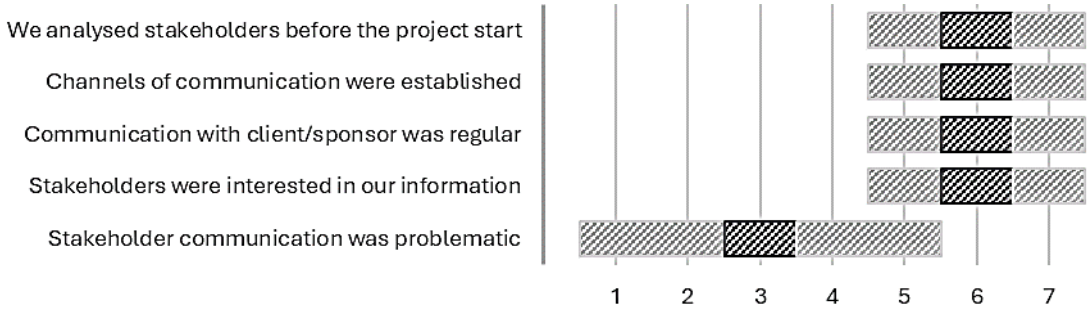

Figure 8. Stakeholder management.

Source: research results.

In addition, responses indicate that projects had regular communication with the client/sponsor (median equal to 6), and that stakeholders were interested in the information they received (median equal to 6). For all these issues, the absolute deviation of the median is 1. Its value indicates the low spread and consistency of respondents' answers. Regarding problems in communication with stakeholders, the median response equals 3. In this case, lower ratings indicate a smaller scale of problems. The absolute deviation here is 2. This suggests that the responses were more scattered, and some respondents rated this issue significantly higher or lower than the median. This result suggests that the experience of communication problems was more varied than that of other stakeholder management issues.

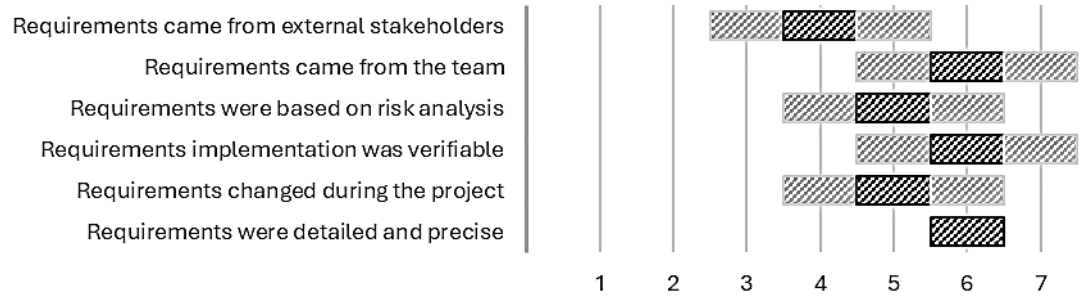

Figure 9. Requirements management.

Source: research results.

Figure 9 shows the results for requirements management. A median of 4 indicates that respondents do not have a unified opinion on whether requirements came mainly from external stakeholders. Responses oscillate around the middle of the scale, suggesting that respondents were divided or unsure - in some cases, requirements may have come mainly from external stakeholders, and in others, not. Most respondents confirm that the requirements were

formulated by the project team and that the implementation of the requirements was verifiable only after the project was completed. On these issues, the median is equal to 6. A median of 5 indicates that respondents mostly agreed that requirements were based on risk analysis and that requirements changed during project implementation. In all these aspects, the mean absolute deviation equals 1, indicating relatively slight variation in responses among respondents.

In addition, most respondents confirm that the requirements were formulated in a detailed and precise manner, as reported by the median of 6. In this regard, the mean absolute deviation of 0 confirms the respondents' agreement and uniform experience.

Although the examination of problems encountered by project teams was not the primary focus of the study, respondents, in their answers to open-ended questions, reported the occurrence of various difficulties. These primarily concerned communication with stakeholders, consistency in team work, and the division of roles. Stakeholders tended to prefer forms of communication that were often different from those proposed by the teams. Individuals from Generation X favoured direct, face-to-face contact, particularly at the beginning of the project. This preference was not immediately apparent to teams composed of individuals from Generation Z. Additionally, in several cases, teams encountered unreliable stakeholders who failed to fulfil their commitments. Not all teams immediately recognised the time-consuming nature of the project. Consequently, some teams commenced work with delays and demonstrated a lack of systematic working habits. This led to project delays and stressful situations caused by the accumulation of numerous tasks within a short timeframe. Not all teams adopted a dynamic approach to role allocation. Some teams established fixed roles, while others did not define roles at all. The latter scenario resulted in blurred responsibilities and missed task deadlines. None of the problems identified stemmed from deficiencies in the methodology under examination.

5. Discussion

This study evaluated a lightweight project management methodology for small-scale projects in environments with limited experience and formal structures—conditions typical of SMEs, start-ups, and nonprofit initiatives. The findings indicate that the methodology was generally perceived as easy to implement, with key tools such as simplified documentation, stakeholder engagement protocols, and risk registers rated positively by participants. These results reinforce earlier calls for minimalist methodologies that reduce bureaucracy and support agility in small teams (Turner et al., 2012; Kolimar et al., 2022).

The findings align with the broader project management literature, emphasising the mismatch between formal methodologies and the resource constraints of smaller organisations (Zaheri et al., 2022; Laporte, Chevalier, 2015). Notably, the study's results echo Rowe's (2020) argument that small projects benefit from tools focused on deliverables, stakeholder clarity, and ongoing feedback cycles—elements embedded in the tested methodology.

The first research question addressed whether the micro.P3.express methodology is straightforward for teams with no project management experience. The high median score of 6 for learning and using the methodology, combined with the low variability (median absolute deviation of 1), highlights its accessibility and intuitiveness. These results correspond to the design principles of the micro.P3.express system, which primarily focuses on simplicity and reduced documentation (micro.P3.express, 2022). In comparison, traditional methodologies such as PRINCE2 or the PMBOK Guide require a higher level of expertise, making them impractical for small and medium-sized organisations, and when project managers lack formal training (Hasibovic, Tanovic, 2019; Zaheri et al., 2022). Tailoring large frameworks does not work well in these situations because it requires higher competencies. The ease of use indicated by the participants aligns with the claim that small and medium-sized enterprises require lightweight methodologies that do not require advanced competencies (Turner et al., 2010). However, slight differences in the assessment of the ease of use of this approach suggest that, despite its simple principles, its implementation in practice may depend, for example, on the project's complexity or the project team's commitment. This aspect highlights the importance of mentoring in the experiment to bridge the gap between theoretical understanding and practical application, which is often missing in real SME conditions (Kozlowski, Matejun, 2016).

The second research question was whether the techniques proposed by the micro.P3.express methodology, i.e. roles (hats), project board, follow-up register and deliverables map, support project execution. Consistently high ratings (median scores of 5 and 6) for these tools confirm their effectiveness in facilitating project management.

The possibility of flexible role assignment with regular exchange of "hats" refers to the multitasking nature of project teams in small and medium-sized organisations, where people often have to handle multiple responsibilities (Turner et al., 2012). This type of flexibility reflects the reality of SMEs, where employees perform operational and project tasks simultaneously (Rowe, 2020). The high median for role exchange (5) confirms the observation that adaptive role structures increase team agility in small projects (Kolimar et al., 2022), e.g. in software development. This suggests that micro.P3.express effectively addresses the need for versatility in resource-constrained environments. The neutral assessment of rigid role allocation (median 4, mad 2) indicates diverse team preferences, which may result from differences in project requirements or team dynamics. This assessment supports the argument that SMEs cannot often implement a structured role framework due to limited staff numbers and a lack of specialist competencies (Marcelino-Sádaba et al., 2014).

The project board was rated intuitive and easy to use, indicating its value as a visual tool supporting planning and control. Respondents were neutral about their preference for a traditional schedule or other board layout, and weekly opening and closing meetings were rated highly. These results confirm that the project board meets the needs of small projects for simple tools that minimise bureaucracy (Rowe, 2020). Unlike complex tools such as Microsoft Project, which are considered too complicated for SMEs, the project board offers clarity and ease of use (Turner et al., 2010). The high ratings for weekly meetings indicate their role in coordinating teams, which is crucial in environments where employees are involved in multiple projects simultaneously (Turner et al., 2012).

The follow-up register received positive evaluations regarding risk identification before the project start, updates during weekly meetings, event management and risk response. Despite the use of the register, the studied teams encountered unforeseen risks. These results indicate that the follow-up register is an effective risk management tool. This is especially important for small projects, which are more exposed to risk due to resource constraints and short schedules (Hwang et al., 2014). The intuitive and straightforward use of the register contrasts with advanced techniques such as CPM or EVM, which are rarely used in SMEs due to their complexity (Turner et al., 2009). Using the register to prepare the team for risks addresses the need for proactive management in SMEs, as Marcelino-Sádaba et al. (2014) described. However, unforeseen risks suggest that the register's effectiveness may be limited in dynamic environments, which requires further research on its adaptation (Bai et al., 2016).

Similarly, the high evaluation of the deliverables map used to define the project outputs refers to the literature emphasising the precise definition of results in small projects (Marcelino-Sádaba et al., 2014). Moreover, the obtained results confirm that small and medium-sized enterprises benefit from a clear focus on results due to limited access to resources, which was the case during the implementation of student initiatives (Zaheri et al., 2022).

The third research question was whether micro.P3.express sufficiently supports stakeholder relationship management. The results, with medians of 6 for thorough stakeholder analysis, regular communication and stakeholder engagement, show that the methodology supports effective stakeholder management. Considering the challenges SMEs face in engaging stakeholders, especially when customers are unfamiliar with project management practices, the obtained results are significant in the context of the overall assessment of the usefulness of mi-cro.P3.express (Kolimar et al., 2022). This contrasts with agile methodologies such as Scrum, which rely heavily on customer engagement and may fail due to misaligned expectations (Hasibovic, Tanovic, 2019). The structured but simple communication protocols of micro.P3.express seem to mitigate such risks. A median of 3 for communication problems, with a higher variance (2), indicates that some teams encountered challenges, possibly due to stakeholder diversity or unclear expectations. This variability mirrors earlier findings of the disproportionate impact of stakeholder risk in small projects (Hwang et al., 2014), suggesting

that while micro.P3.express facilitates stakeholder management, its effectiveness may depend on the team's communication skills or the project's external environment.

The fourth research question aimed to investigate the assessment of the micro.P3.express methodology's support for project requirements management. Positive assessments regarding precise requirements formulation and their verification after the project completion emphasise the micro.P3.express approach's adaptability to provide clarity in a domain where SMEs often struggle with ambiguous customer needs (Zaheri et al., 2022). Moderate agreement on requirements changing during projects and their formulation based on risk reflects the dynamic nature of small projects, where adaptability is key (Turner et al., 2010). A neutral assessment of whether requirements come mainly from external stakeholders suggests that teams draw from internal and external sources. This confirms flexibility and is consistent with Rowe's (2020) recommendations for adaptive requirements management in small projects. Compared to waterfall methodologies that struggle with changes during a project, or agile approaches that can overwhelm small organisations with constantly changing requirements, micro.P3.express strikes a balance by allowing iterative updates within a structured framework (Anwer et al., 2017). This balance is especially valuable for SMEs where resource constraints require meeting requirements with minimal rework.

These findings also offer relevant implications for the theoretical development of project management methodologies tailored to small organisations. The results provide empirical support for the emerging shift in the literature from universal, process-intensive frameworks towards context-specific, lightweight approaches grounded in contingency theory. In particular, they validate the proposition that the effectiveness of project management stems less from methodological comprehensiveness and more from contextual suitability – especially in terms of simplicity, cognitive accessibility, and adaptability. The strong usability and perceived value of micro.P3.express among novice teams align with Rowe's (2020) minimalist paradigm, indicating that project success in micro-environments may depend more on iterative learning and stakeholder coordination than on formal process maturity. This highlights the need to advance theoretical models that conceptualise "methodological adequacy" as context-dependent, rather than as an absolute standard derived from large-organisation practices.

6. Conclusions

This study examined the application and perceived usefulness of a simplified project management methodology tailored to small projects implemented under resource and competency constraints. Through an experimental approach involving real-world project execution by student teams, the study generated empirical insights into the usability, effectiveness, and limitations of lightweight project tools in micro-project contexts.

The findings contribute to project management theory by providing rare experimental evidence on the implementation of minimalist methodologies. Unlike traditional frameworks that require tailoring and extensive experience, the methodology tested here was accessible to novice teams and supported core project management activities – planning, monitoring, and stakeholder engagement – without introducing unnecessary complexity. These results support the argument that purpose-built, lightweight methodologies may be more appropriate for small organisations than adapted versions of enterprise-scale frameworks.

From a practical perspective, the study suggests that small enterprises and nonprofit organisations can benefit from adopting streamlined methods that emphasise clarity, frequent feedback, and simple documentation. These tools, when supported by basic training and stakeholder coordination, can enhance project delivery even in the absence of formal project management infrastructure.

Nevertheless, the study has several limitations. The sample consisted of student teams operating in an educational context, which may not fully replicate the pressures, stakeholder dynamics, or accountability found in commercial environments. Additionally, mentor involvement may have enhanced performance beyond what the methodology alone would yield. These constraints limit the generalizability of findings and highlight the need for further research.

Future studies should replicate this work in professional environments, com-paring lightweight methodologies across industries and team structures. Mixed-method approaches incorporating interviews, longitudinal tracking, and outcome-based evaluation would deepen understanding of the mechanisms driving success or failure in small project contexts. Moreover, exploring how minimalist approaches can integrate with digital tools or hybrid models may offer new pathways for innovation in project management practice.

Competing interest statement

The authors declare that they have no competing interests.

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References

1. Anwer, F., Aftab, S., Ali, I. (2017). Proposal of a Tailored Extreme Programming Model for Small Projects. *Int. J. Comput. Appl. 171*, pp. 23-27. https://doi.org/10.5120/ijca2017915112
2. Bai, J., So, K.C., Tang, C. (2016). A queueing model for managing small projects under uncertainties. *Eur. J. Oper. Res. 253*, pp. 777-790. https://doi.org/10.1016/j.ejor.2016.02.052
3. Hasibovic, A.C., Tanovic, A. (2019). *PRINCE2 vs Scrum in digital business transformation.* 2019 42nd International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO). Presented at the 2019 42nd International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), IEEE, Opatija, Croatia, pp. 1514-1518. https://doi.org/10.23919/MIPRO.2019.8756716
4. Hwang, B.-G., Zhao, X., Toh, L.P. (2014). Risk management in small construction projects in Singapore: Status, barriers and impact. *Int. J. Proj. Manag. 32*, pp. 116-124. https://doi.org/10.1016/j.ijproman.2013.01.007
5. Jovanovic, P., Beric, I. (2018). Analysis of the available project management methodologies. *Manag. J. Sustain. Bus. Manag. Solut. Emerg. Econ. 23*, pp. 1-10. https://doi.org/10.7595/management.fon.2018.0027
6. Kolimar, O., Kusnirak, K., Kucera, E., Haffner, O. (2022). *Delivery Team Management on Small Software Development Projects in Practice.* 2022 Cybernetics & Informatics (K&I). Presented at the 2022 Cybernetics & Informatics (K&I), IEEE, Visegrád, Hungary, pp. 1-6. https://doi.org/10.1109/KI55792.2022.9925969
7. Kozlowski, R., Matejun, M. (2016). Characteristic features of project management in small and medium-sized enterprises. *EM Ekon. Manag., 19*, pp. 33-48. https://doi.org/10.15240/tul/001/2016-1-003
8. Kutsch, E., Maylor, H., Weyer, B., Lupson, J. (2011). Performers, trackers, lemmings and the lost: Sustained false optimism in forecasting project outcomes — Evidence from a quasi-experiment. *Int. J. Proj. Manag., 29*, pp. 1070-1081. https://doi.org/10.1016/mj.ijproman.2011.01.010
9. Laporte, C.Y., Chevalier, F. (2015). An Innovative Approach to the Development of Project Management Processes for Small-Scale Projects in a Large Engineering Company. In: K. Jakobs (Ed.), *Effective Standardization Management in Corporate Settings: Advances in IT Standards and Standardization Research*. IGI Global. https://doi.org/10.4018/978-1-4666-9737-9

10. Marcelino-Sádaba, S., Pérez-Ezcurdia, A., Echeverría Lazcano, A.M., Villanueva, P. (2014). Project risk management methodology for small firms. *Int. J. Proj. Manag., 32*, pp. 327-340. https://doi.org/10.1016/j.ijproman.2013.05.009
11. Maslennikov, V.V., Popova, E.V., Kalinina, I.A. (2022). Classic Project Management Based on PMBOK 7.0. In: *Towards an Increased Security: Green Innovations, Intellectual Property Protection and Information Security*. Presented at the Institute of Scientific Communications Conference, Springer, Cham, pp. 835-840. https://doi.org/10.1007/978-3-030-93155-1_90
12. *micro.P3.express - minimalist project management for micro projects* (2022). https://micro.p3.express/, 13.04.2025.
13. Piwowar-Sulej, K. (2021). Organizational culture and project management methodology: research in the financial industry. *Int. J. Manag. Proj. Bus., 14*, pp. 1270-1289. https://doi.org/10.1108/IJMPB-08-2020-0252
14. Rad, N., Turley, F. (2021). *P3.express Manual*.
15. Rode, A.L.G., Jensby, A., Svejvig, P. (2024). Evaluating a project management methodology to improve project performance. *Int. J. Manag. Proj. Bus., 17*, pp. 405-429. https://doi.org/10.1108/IJMPB-08-2023-0182
16. Rowe, S.F. (2020). *Project management for small projects*. Oakland: Berrett-Koehler Publishers.
17. Sane, S. (2020). Effect of using project management tools and techniques on SMEs performance in developing country context. *Int. J. Manag. Proj. Bus., 13*, pp. 453-466. https://doi.org/10.1108/IJMPB-11-2018-0251
18. Turner, R., Ledwith, A., Kelly, J. (2009). Project management in small to medium- sized enterprises: A comparison between firms by size and industry. *Int. J. Manag. Proj. Bus., 2*, pp. 282-296. https://doi.org/10.1108/17538370910949301
19. Turner, R., Ledwith, A., Kelly, J. (2010). Project management in small to medium-sized enterprises: Matching processes to the nature of the firm. *Int. J. Proj. Manag., 28*, pp. 744-755. https://doi.org/10.1016/j.ijproman.2010.06.005
20. Turner, R., Ledwith, A., Kelly, J. (2012). Project management in small to medium- sized enterprises: Tailoring the practices to the size of company. *Manag. Decis., 50*, pp. 942-957. https://doi.org/10.1108/00251741211227627
21. Zaheri, A., Rojhani, M., Rowe, S.F. (2022). Evaluating PMBOK for Small Project Management. *Int. J. Ind. Eng. Prod. Res., 33*, pp. 51-67. https://doi.org/10.22068/ijiepr.33.1.9

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AI MEETS HR – SYSTEMATIC REVIEW OF IMPLEMENTATION AND OPERATIONAL BARRIERS

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Purpose: This paper aims to explore the main barriers to the adoption and practical functioning of artificial intelligence in HRM. The goal is to provide a structured, multidimensional understanding of the challenges organizations face when implementing AI in HR processes.
Design/methodology/approach: The study is based on a systematic literature review of 24 peer-reviewed academic publications from 2020 to 2024. A thematic analysis was employed to identify and categorize barriers, drawing from empirical and conceptual research across different sectors and regions.
Findings: The review reveals a complex landscape of barriers spanning psychological, social, organizational, technological, and legal domains. These include lack of digital competencies among HR professionals, poor data quality, resistance to change, low trust in algorithmic systems, and ethical concerns. The findings highlight that AI implementation requires organizational and cultural transformation.
Research limitations/implications: The findings are limited by the scope and diversity of the selected literature, which is predominantly English-language and spans various contexts.
Practical implications: For successful AI adoption in HR, organizations must invest in digital and analytical skill development, ensure data quality, promote transparency and explainability in AI systems, and actively involve stakeholders in the implementation process.
Social implications: The integration of AI into HRM carries significant social implications, particularly regarding fairness, employee autonomy, and workplace relationships. Algorithmic bias may reinforce existing inequalities, while the automation of human-centric processes risks dehumanizing HR practices. Additionally, concerns about privacy, surveillance, and job insecurity can lead to resistance and technostress among employees.
Originality/value: This paper contributes a synthesized and structured analysis of current academic insights on AI-related challenges in HRM. It offers a foundation for evidence-based strategies, highlights research gaps, and encourages a systemic, human-centred approach to digital transformation in HR.
Keywords: Artificial intelligence, Human resource management, AI implementation, Barriers, Organizational transformation.
Category of the paper: Research paper.

1. Introduction

The modern economy is characterised by an increasing pace of technological change, which compels organisations to implement more advanced solutions, including those based on artificial intelligence (AI). Digital transformation also affects human resource management (HRM), introducing new challenges, technological expectations, and opportunities. Organisations making more intensive use of information technologies and data-driven capabilities are confronted with a key question: how can they effectively manage human resources, attract and develop talent, and make sound personnel decisions in an environment of uncertainty and rapid change?

The application of intelligent solutions in business is widespread in areas such as market analysis, product development, marketing, sales, customer service, and logistics. The introduction of AI can contribute to improved efficiency, greater decision-making precision, and increased customer and employee satisfaction. Therefore, it is no surprise that this technology has also gained attention in the HR context, where AI can support or, in some cases, even redefine the way personnel functions are carried out (Verma et al., 2023).

Despite growing interest in and the recognised potential of AI technologies, their implementation and everyday use in HR remains limited (Murugesan et al., 2023). This indicates several barriers and challenges that hinder the widespread adoption of these solutions. Although such obstacles often stay in the shadow of optimistic digital transformation visions, they appear to have a tangible impact on HR practice.

Identifying these barriers has thus become an important area of research, both from a scientific and a practical perspective. This gap in the literature allows for formulating a research problem focused on identifying the limitations and risks associated with the implementation and use of AI in HRM. To address this problem, the following research questions were posed:

RQ1: What factors limit the implementation of AI solutions in the HR domain?

RQ2: What factors most frequently hinder the everyday use of AI in HR activities?

Answering these questions will make it possible to identify key obstacles and understand their origins and characteristics knowledge that, in turn, can support the development of effective mitigation strategies. A deeper understanding of AI-related barriers in HR may serve as a foundation for a responsible and effective digital transformation of the HR function.

2. Artificial Intelligence in Human Resource Management

From a semantic perspective, artificial intelligence (AI) can be defined as a set of characteristics of intelligence or parts thereof attributed to an unnatural entity. According to the Merriam-Webster Dictionary (2023), AI is the capability of a machine to imitate intelligent human behaviour. One of the pioneers in the field, John McCarthy, defined AI as "the science and engineering of making intelligent machines, especially intelligent computer programs". In a project proposal from 1955, he stated that the goal of research was to create machines capable of using language, forming abstractions, and solving problems that had previously been reserved for humans (McCarthy et al., 1955).

AI can thus be understood as an attempt to replicate human cognitive processes in a machine not as a science-fiction concept but as a practical, interdisciplinary idea. Murphy (2012) describes AI as a technology that enables machines to perform tasks requiring human intelligence. Among the techniques used are machine learning, natural language processing, computer vision, and robotics. AI systems are those capable of learning from data and improving their performance over time, making decisions based on information and data and solving problems creatively and effectively.

AI algorithms are instructions that allow machines to self-improve based on input data. Key features of AI include adaptability, the ability to interpret context, natural interaction with humans, and, in some cases, autonomous decision-making.

The added value of AI stems from its ability to integrate data from various sources (e.g., ERP, CRM, social media, mobile devices) and analyse it to identify patterns and support decision-making, often at a level of complexity unattainable by humans.

The first references to AI use in HRM date back to 1994 and concerned expert systems. In subsequent years, developments included fuzzy logic (2000), neural networks (2001), data mining (2006), genetic algorithms (2008), and machine learning (2011) (Quamar et al., 2021). The dynamic growth of computing power and access to large datasets enabled the popularisation of generative solutions such as chatbots and virtual assistants. Although many of these technologies existed earlier, they have only recently become widely accessible commercially.

Due to the diversity of applications, providing a definitive definition of AI in HRM is difficult. It may refer to comprehensive human resource management systems and specialised applications automating a single process. The diversity of solutions and the degree of integration make comparing statistical data challenging.

AI technologies are present in nearly every area of HRM and at all levels of management: from strategic planning (Chakraborty et al., 2020; Gélinas et al., 2022; Verma et al., 2023) through recruitment and selection (Goncalves et al., 2022; Bhatt, 2023; Li et al., 2023), training and development (Faqihi, Miah, 2023; Murugesan et al., 2023), performance appraisal

(Böhmer, Schinnenburg, 2023), and compensation (Gélinas et al., 2022), to employee relations as well as legal and ethical issues. The literature emphasises that AI supports the entire employee life cycle, from attracting candidates to offboarding, integrating tasks, and increasing organisational efficiency (Chakraborty et al., 2020; Li et al., 2023).

When discussing the use of AI in HR, it is important to examine the type of work being performed. The literature highlights three main domains: automation of operational processes, data analysis, and support or automation of decision-making processes. AI systems can combine these functions, creating synergy from data processing and interpretation to taking action (Shaw et al., 2019). However, this approach does not imply full autonomy of systems; the dominant model remains one of human-machine collaboration, a role that continues to evolve. The emerging concept of hybrid HR emphasises the complementarity of human and technological functions.

In the operational domain, AI can automate various administrative and transactional tasks. For example, this technology is used in document creation and circulation (e.g., job postings, newsletters, contracts), meeting organisation and documentation, performance appraisal processes, document archiving, and HR and payroll services, including salary and benefits calculations. AI can also support communication between employees and the HR department, for instance, through chatbots that handle employee inquiries, complaints, and requests (Korzyński et al., 2023).

In data analysis, AI enables the processing large volumes of information from internal (HRIS systems, operational data) and external sources (labour market data, benchmarks). This facilitates more accurate candidate evaluations not only in terms of competence but also cultural fit. AI also supports training needs analysis, talent identification, career path planning, and the prediction of workplace risks. By analysing data from sensors, cameras, and other sources, these systems can contribute to occupational health and safety efforts (Murugesan et al., 2023).

AI is particularly significant in People Analytics and Compensation & Benefits. In the first case, AI allows for predicting employee behaviour (e.g., absenteeism, turnover) and measuring productivity for instance, by analysing work time and task completion. This enables continuous process adjustments and the identification of areas for improvement. In compensation, AI systems can analyse the alignment of pay policies with market benchmarks, forecast the impact of benefits on employee performance, and support accurate salary calculations, reducing the risk of errors (Murugesan et al., 2023).

The use of AI in decision-making processes is primarily associated with the potential to reduce subjectivity and improve decision accuracy. Algorithms can assist in matching candidates to positions, recommending bonuses, or making HR decisions based on performance data. Such approaches support rational workforce management and cost-effectiveness (Kshetri, 2021).

The integration of AI technologies into HRM, however, goes beyond automation. AI can act as an integrator of HR functions, connecting data, processes, and decisions into a cohesive whole. These systems can deliver personalised HR services in real-time, from training recommendations and career development suggestions to modelling flexible working conditions. Such solutions improve employee experience, enhancing engagement, retention, and performance (Kshetri, 2021). These capabilities are key drivers of interest in AI technologies in HR as tools for efficiency and as transformative elements in managing the HR function.

3. Research Methodology

From A systematic literature review was conducted to address the research questions posed in this study, allowing for a rigorous and structured analysis of the existing scientific body of knowledge in the relevant domain (Czakon, 2015). This review followed an established research procedure, emphasising transparency in the selection process, clearly defined inclusion criteria, and thematic content analysis.

The analysis focused on academic publications exploring barriers and risks associated with the implementation and use of artificial intelligence in human resource management (HRM). The empirical material was sourced from full-text databases Scopus and Web of Science (WoS), which are considered the most comprehensive repositories indexing peer-reviewed management literature (Mongeon, Paul-Hus, 2016). The choice of these databases was motivated by their thematic coverage and the possibility of integrating bibliographic data from various types of publications (articles, book chapters, conference proceedings) into a unified analytical format.

In both databases, an identical search query string was applied. It included four key components: references to artificial intelligence, HRM functions, the application phase, and potential limitations. The full query was as follows: (“AI” OR “Artificial Intelligence”) AND (“HR” OR “HRM” OR “Human Resources” OR “Human Resources Management” OR “People Management” OR “Personnel Management”) AND (“implementation” OR “adoption” OR “application” OR “launch” OR “usage” OR “utilisation”) AND (“limitation” OR “problems” OR “difficulties” OR “barriers”).

The search results were refined by applying additional selection criteria in the next stage of the database development process. Only publications published between 2020 and 2024, written in English and classified as peer-reviewed journal articles, were included. To further increase the relevance of the selected materials, thematic filtering was applied based on the subject classifications of each database. For the Scopus database, the category “Business, Management & Accounting” was selected, while in Web of Science (WoS), the filters “Business” and

"Management" were applied. After implementing these initial filters, 60 results were retrieved from Scopus and 39 from Web of Science. Duplicate records were identified and removed, reducing the dataset by 26 entries. The remaining publications were screened through abstract analysis to assess their alignment with the research focus of this review. At this stage, 40 articles were excluded due to thematic mismatch.

The selection process also involved exclusion criteria to eliminate studies that did not meet the thematic assumptions of this review. The following types of publications were excluded:

- Articles focused on technologies without explicit reference to artificial intelligence.
- Publications discussing specific AI technologies without reference to their use in HR.
- Studies examining AI in HR without reference to barriers, limitations, or challenges.

Ultimately, 33 academic articles were qualified for full-text analysis, of which 24 were selected for final inclusion after in-depth verification based on their conceptual, methodological, and thematic alignment with the scope of this review (Table 1).

Table 1.
Searching strategy

Procedure phase	**Description**
Phrase Search	N = 932
First-Level Inclusion Criteria	Publication year: All years from 2020 to 2024 Document type: Article Language: English N = 321
Second-Level Inclusion Criteria	Scopus subject area: Business, Management & Accounting, Web of Science Categories: Business, Management, N = 80
Duplicate Documents	Files cleaning (after all duplicate records are removed) N = 68
Abstract analysis	After files removed, N = 31
Full-text analysis	Final sample selected for further analysis: N = 24

Source: Own study.

A large number of excluded publications resulted from the previously mentioned ambiguity surrounding the definition of artificial intelligence and the growing popularity of the topic itself, which has led to frequent overuse of AI-related terminology. For example, some articles referenced AI only marginally, most often in the abstract, as a potential direction for future development, without any substantial discussion of implementation or actual use of AI in HR.

Among the 24 selected publications, three were published in 2020, one in 2021, two in 2022, six in 2023, and twelve in 2024. The increase in the number of publications appears to reflect the growing interest in and development of AI-based technologies, suggesting a further expansion of research in this field, thus reinforcing the relevance of the present study.

The full-text analysis revealed that 23 of the 24 articles identified barriers related to the implementation of AI in HR, and 15 linked to the practical use of already implemented systems. Most of the reviewed studies were empirical (16), including one experimental study and one case study, while the rest employed qualitative or quantitative methods (e.g., surveys and interviews). The remaining eight publications were theoretical or literature-based reviews.

The qualitative analysis of the material involved manual extraction of elements identified by the authors as barriers, difficulties, or limitations associated with AI implementation or use in HR-related contexts. Unique items were identified, and descriptions were assigned in a manner consistent with the reviewed sources. The preliminary analysis revealed significant variation in terminology, levels of detail, and conceptual scope, which prompted the researchers to adopt thematic analysis to organize and synthesize the data.

Thematic analysis, following the approach of Clarke and Braun (2016), facilitates the identification of patterns across qualitative data, integrating diverse sources and perspectives, both empirical and theoretical. In the initial phase, short, precise codes were generated to describe individual data units. These codes were then grouped into potential themes, which were subsequently organized hierarchically according to the method proposed by Attride-Stirling (2001), allowing for identifying key problem areas. In the pre-implementation phase, the main obstacles included social barriers, organizational and managerial barriers, as well as technological barriers. In the post-implementation phase, the barriers identified were primarily of a social nature, along with operational and functional barriers that emerged during the actual use of AI systems. In the process's final phase, the assigned themes' consistency and validity were reviewed, and the names and definitions were refined. The outcome was a consolidated catalogue of 21 barriers and limitations, ensuring internal coherence across the research procedure.

4. Discussion of Findings

4.1. Barriers and Limitations in the Implementation Phase of AI Solutions in HR Domains

A necessary condition for an organization to even consider implementing AI technologies in HR is an economic assessment, which typically considers factors such as costs, time, expected performance, customer satisfaction, decision-making accuracy, predictive capabilities, and the technological feasibility of implementation given the available resources (Cubric, 2020). Among the reviewed literature, only a few authors explicitly emphasize the economic dimension, and even then, it is usually presented as part of the pre-implementation analysis or as a motivating factor for managers. However, researchers tend to shift their focus from economic considerations to managerial attitudes during the actual implementation phase of AI technologies, which become the primary subject of investigation. For this reason, financial factors were not further explored in the subsequent stages of the discussion.

Table 2.
AI Implementation Barriers in HR

Category	Barrier	Source
Social Barriers	Fear of job loss (job insecurity)	(Qamar et al., 2021; Li et al., 2023; Rukadikar, Khandelwal, 2024)
	Resistance to change	(Qamar et al., 2021; Li et al., 2023; Rukadikar, Khandelwal, 2024; Suseno et al., 2022; Bazrkar, 2024)
	Low level of trust in AI / concerns about control	(Qamar et al., 2021; Rukadikar, Khandelwal, 2024; Cubric, 2020; Angelova et al., 2023; Islam et al., 2023; Paramita, 2024; Dutta, Mishra, 2023; Malin et al., 2023)
	Ethical concerns (discrimination, lack of transparency, privacy)	(Qamar et al., 2021; Li et al., 2023; Rukadikar, Khandelwal, 2024; Marler, 2024; Gélinas et al., 2022; Kshetri, 2021)
	Perceived threat to human decision-making autonomy	(Qamar et al., 2021; Angelova et al., 2023; Dutta, Poyil, 2023)
	Technostress / AI anxiety	(Rukadikar, Khandelwal, 2024; Suseno et al., 2022; Destriani et al., 2024)
Managerial and organisational Barriers	Lack of technological competencies (among managers/employees)	(Li et al., 2023; Rukadikar, Khandelwal, 2024; Suseno et al., 2022; Böhmer, Schinnenburg, 2023; Destriani et al., 2024; Cao, Nguyen, 2024; Bazrkar, 2024; Verma et al., 2023; Oswald et al., 2020)
	Absence of a clear strategy or vision for AI implementation in HR	(Böhmer, Schinnenburg, 2023; Angelova et al., 2023; Cao, Nguyen, 2024; Bhatt, 2023; Verma et al., 2023)
	Lack of managerial engagement and decision-making support	(Bhatt, 2023)
	Concerns about the diminishing role of HR ("dehumanisation of HR")	(Paramita, 2024; Dutta, Poyil, 2023)
Technological Barriers	Lack of AI system transparency ("black-box problem")	(Rukadikar, Khandelwal, 2024; Islam et al., 2023; Marler, 2024; Gélinas et al., 2022; Malin et al., 2023)
	Poor data quality/lack of training data	(Cubric, 2020; Destriani et al., 2024; Gélinas et al., 2022; Kshetri, 2021)
	High implementation costs vs. low return on investment (ROI)	(Yadav, Kapoor, 2024; Kshetri, 2021)
	Incompatibility with existing IT systems	(Cubric, 2020; Destriani et al., 2024; Yadav, Kapoor, 2024; Yue, 2023)

Source: Own study.

The analysis of sources confirms that implementing artificial intelligence (AI)-based systems in human resource management (HRM) encounters numerous limitations. These limitations emerge as early as the planning and decision-making phases of implementation. The barriers are complex, encompassing social, organisational, and technological factors (Table 2). Their interdependencies reinforce each other and reduce an organisation's readiness for digital transformation.

Among the social barriers, one of the key obstacles to AI implementation in HR is the fact that "Employees may be afraid of being replaced by AI" (Li et al., 2023), along with concerns about transferring many operations outside the HR function (Dutta, Poyil, 2023). It is suggested that automation of tasks previously performed by humans may lead to simplifying responsibilities and a diminished sense of professional agency and value. "Fear that smart machines have started to replace humans in the workplace is another barrier to AI implementation" (Suseno et al., 2022). Such fears are intensified when employees lack the necessary technological and analytical competencies. This leads to technostress, a loss of

control, and fears that "AI will remove their autonomy" (Suseno et al., 2022). These concerns contribute to negative attitudes and a lack of trust in AI among employees and customers. "A lack of trust would reduce participants' emotive involvement, which is how they interpret the AI offering" (Dutta, Poyil, 2023). This challenge is related to technostress, chronic stress triggered by the need to adapt to changing tools and methods, lack of control, and efficiency pressure (Destriani et al., 2024). Paradoxically, technologies intended to support employee development generate new competency requirements, forcing constant knowledge updates and redefining professional roles. As a result, cognitive overload, reduced job satisfaction, and work-life imbalance are common.

In addition to psychological factors, organisational barriers are also significant. These include a lack of technological competencies among both managers and employees, the absence of strategy or vision for AI implementation, insufficient top management support, and concerns about the diminishing role of HR in the organisation.

Numerous authors emphasise that a lack of technological and analytical skills among HR professionals is a critical weakness of the field (Li et al., 2023; Rukadikar, Khandelwal, 2024; Suseno et al., 2022; Böhmer, Schinnenburg, 2023; Destriani et al., 2024; Cao, Nguyen, 2024; Bazrkar, 2024; Verma et al., 2023; Oswald et al., 2020). As Li et al. (2023) notes, "Lack of technological and digital skills may lead them to refuse to use AI." This competency gap also affects management, which often lacks a clear understanding of AI systems' capabilities and limitations. According to Suseno et al. (2022), "HR professionals need support and encouragement from leadership to fully integrate AI". A. Islam et al. (2023) further confirm this by stating that "Top management support emerges as the most significant factor in the adoption of AI technology in organisations". A lack of expertise is a barrier and a root cause of other social and technological limitations. Literature highlights that managerial attitudes, including openness to change, levels of anxiety, and expectations are just as critical as technical challenges (Cubric, 2020; Bhatt, 2023).

The final organizational barrier is the absence of a clear strategy or roadmap for AI adoption. As Yaday and Kapoor (2024) emphasize, "AI initiative strategy should also be launched by top management. There is evidence that regulations are effective in promoting AI technology". Managers who have experienced the benefits of intelligent systems are more likely to recognize the value of aligning AI with their HR strategies (Cao, Nguyen, 2024).

While the barriers mentioned above are primarily social and organizational, others are directly linked to the technological architecture and the nature of the data used. Foremost among these is the "black-box problem". which refers to the lack of transparency in AI system operations. This creates distance and distrust among employees who perceive algorithmic decision-making as opaque and difficult to understand (Rukadikar, Khandelwal, 2024; Islam et al., 2023; Marler, 2024; Gélinas et al., 2022; Malin et al., 2023). Technological solutions like machine learning are inherently complex, "limiting people's technological understanding, leading to critical information asymmetries" (Qamar et al., 2021). As Marler (2024) points out,

"It is not enough to say the AI algorithm produced the answer". A lack of understanding of how AI reaches its conclusions can lead to justifiable concerns (Malin et al., 2023).

Another major limitation in implementing AI solutions is the lack of data, poor data quality, fragmentation, and difficulty in system integration (Cubric, 2020; Destriani et al., 2024; Gélinas et al., 2022; Kshetri, 2021). The data problem is directly tied to technological competencies. High-value data results from the engagement of competent and informed staff in HR departments and across all organizational units contributing to AI systems. A shortage of qualified professionals among HR specialists and managers is a core cause of data deficits. These competencies encompass data collection and processing and an awareness of organizational data culture. Researchers argue that the development of HR analytics is limited by a short-term approach to data management, challenges in maintaining data quality, and gaps in analytical skills (Conte, Siano, 2023). HRM processes rely on data from HRIS (Human Resource Information Systems) and other departmental systems. This makes data coordination and integration across disparate, inconsistent, and often unstructured sources a significant challenge especially when data are stored in different formats and languages and are not covered by formal audit procedures (Oswald et al., 2020). Given the magnitude of technical and organizational factors, maintaining data quality often becomes unmanageable for standard HR departments. Data quality is crucial because modern AI systems, especially those based on machine learning, require large datasets to produce reliable recommendations. Data scarcity, incompleteness, and poor-quality lead to flawed models and inaccurate outputs (Dutta, Mishra, 2023), potentially resulting in serious consequences for organizational decision-making. AI algorithms themselves are not immune to bias. Historical data shape decisions made by AI. If those data are unfair or biased, algorithms may reproduce and reinforce existing prejudices or discriminatory patterns embedded in the original datasets (Gélinas et al., 2022).

All the above factors pose significant limitations to implementing AI in HRM, which was the focus of the study's first research question.

4.2. Barriers and Limitations Related to the Functioning of AI in HR Domains

Organisations often encounter new challenges after implementing artificial intelligence systems in human resource management. These barriers emerge during the daily use of AI and are socio-psychological and operational-functional (Table 3).

Table 3.
Operational Barriers to AI in HR

Category	Barrier	Source
Social Barriers	Perceived unfairness of AI-driven decisions (e.g., in recruitment)	(Rukadikar, Khandelwal, 2024; Paramita, 2024; Gélinas et al., 2022; Malin et al., 2023)
	Dehumanisation of HR interactions	(Rukadikar, Khandelwal, 2024; Paramita, 2024; Dutta, Mishra, 2023)
	Lack of trust in AI system outputs	(Cubric, 2020; Rukadikar, Khandelwal, 2024; Suseno et al., 2022; Dutta, Mishra, 2023; Malin et al., 2023)

Cont. table 3.

Managerial and organizational Barriers	Difficulty in interpreting AI results by HR professionals	(Böhmer, Schinnenburg, 2023; Oswald et al., 2020; Malin et al., 2023)
	Overreliance on technology/loss of HR team autonomy	(Li et al., 2023; Paramita, 2024; Dutta, Poyil, 2023; Malin et al., 2023)
	Challenges with updating, adapting, and scaling AI systems	(Destriani et al., 2024; Gélinas et al., 2022; Verma et al., 2023)
	Inability to adjust algorithms to the organisational context	(Yadav, Kapoor, 2024; Bhatt, 2023; Verma et al., 2023)

Source: Own study.

The use of intelligent technologies in HR is associated not only with the challenges of implementation but also with their everyday use. The literature identifies two main categories of such barriers: social (social and relational) and managerial (organizational). Among the most frequently mentioned social factors is the lack of trust in the results and decisions generated by AI. HR employees and managers often question the reliability and neutrality of AI systems, which limits their full utilization (Malin et al., 2023). Serious concerns also arise from processing personal data collected from multiple sources, such as computer logs, sensors, messaging platforms, or monitoring systems, which can evoke associations with excessive surveillance and privacy violations. As a result, employees with strong positions in the labor market may leave the company if they feel overly monitored in their performance (Böhmer, Schinnenburg, 2023). The broad scope of data analyzed by AI systems may lead to suspicions of surveillance, especially when there is a lack of transparency in data usage and storage. In this context, "Trust and communication are key to effective AI engagement in HR" (Dutta, Mishra, 2023). The lack of trust is often linked to the perception that AI-generated outcomes are unfair, impersonal, and difficult to challenge. This is particularly relevant in recruitment, candidate selection, and performance appraisal processes, where users highlight the absence of social context and the excessive standardization of algorithms as potential sources of unequal treatment. "Biased algorithms can support inequality and discrimination […] transparency is essential to retaining applicants' confidence" (Rukadikar, Khandelwal, 2024). Gélinas et al. (2022) point to the issue of systemic biases embedded in algorithmic decision-making. This is connected to the problem of algorithmic discrimination, which may result in bias against employees based on gender, age, ethnicity, or other sensitive attributes (Kshetri, 2021). If historical data reflect patterns of nepotism, prejudice, or informal decision-making, algorithms may unintentionally perpetuate and reinforce them, creating a paradox in which a system designed to reduce human error replicates it (Kshetri, 2021; Paramita et al., 2024).

Another issue with implementing AI is the dehumanization of HR relationships and processes. Automating interactions through chatbots, assessment systems, or digital recommendations reduces opportunities for empathetic dialogue and personalized employee engagement. "Lack of human-to-human interaction in AI-driven processes can lead to impersonal connection and low trust" (Paramita et al., 2024). Digital isolation in employee development may also lead to reduced creativity and innovation.

One of the most frequently identified managerial challenges is interpreting AI-generated outputs, particularly when the algorithm's accuracy is perceived as flawed (Dietvorst et al., 2018; Prahl, Van Swol, 2017). This highlights the need to develop algorithmic literacy that fosters a reciprocal relationship between employees and algorithms, including human-assisted and machine-assisted roles (Paramita, 2024). Böhmer (2023) emphasizes that AI systems rely on complex mathematical models whose inner workings remain opaque to most users. Self-learning algorithms function as a "black box," with their reasoning processes difficult to understand even for specialists (Böhmer, Schinnenburg, 2023). As a result, organizations must invest in digital skills and user education, which poses an additional burden for HR departments. This issue is closely tied to data quality. Low-quality data with incomplete, outdated, or non-representative inputs can lead to incorrect conclusions and recommendations. Algorithms trained on such data may replicate systemic errors rather than eliminate them, posing a significant threat to the objectivity of HR processes. Functional limitations are also related to the inflexibility of AI systems, which rely on historical data and often fail to account for contextual, cultural, or individual variations.

Another post-implementation barrier in HR practice is the gradual transfer of responsibility to AI systems, simplifying and automating many employee tasks (Dutta, Poyil, 2023). This may result in the erosion of critical thinking and the neglect of intuition and experience in decision-making. Ardichvilli (2022) warns that the increasing delegation of tasks to AI may also limit employees' opportunities to develop competencies, share knowledge, and engage in intellectually meaningful work. "Automation of processes that leads to machines taking over tasks previously reserved for humans may contribute to job loss or reduction in job complexity" (Ardichvilli, 2022). As Chowdhury et al. (2023) note, managers supported by AI systems are more likely to make questionable decisions by shifting part of the responsibility to the technology.

At the systemic level, challenges such as scaling and adapting AI systems to different organizational sizes remain significant (Gélinas et al., 2022). As Malin et al. (2023) observe, "Maintenance costs are a disadvantage" because "Somebody has to take care of this technological achievement and provide content continuously." Feeding AI systems with new knowledge must align with evolving user expectations (Malin et al., 2023), and difficulties in this regard reduce algorithmic usefulness (Yadav, Kapoor, 2024), further fueling concerns about fairness and the lack of flexibility in AI systems tailored to generic use cases (Bhatt, 2023). Managerial and organizational barriers are both technical and competency related. Addressing them requires developing analytical skills, system-level AI management, and cultivating a data-driven learning culture.

The above analysis answers the second research question: What factors most frequently hinder the everyday use of AI in HR activities?

5. Conclusions and Recommendations

The following conclusions, recommendations, and research directions can be formulated considering the literature review. The analysis of publications concerning the implementation and use of artificial intelligence (AI) in human resource management (HRM) reveals a wide range of barriers from social to organizational and technological (Figure 1).

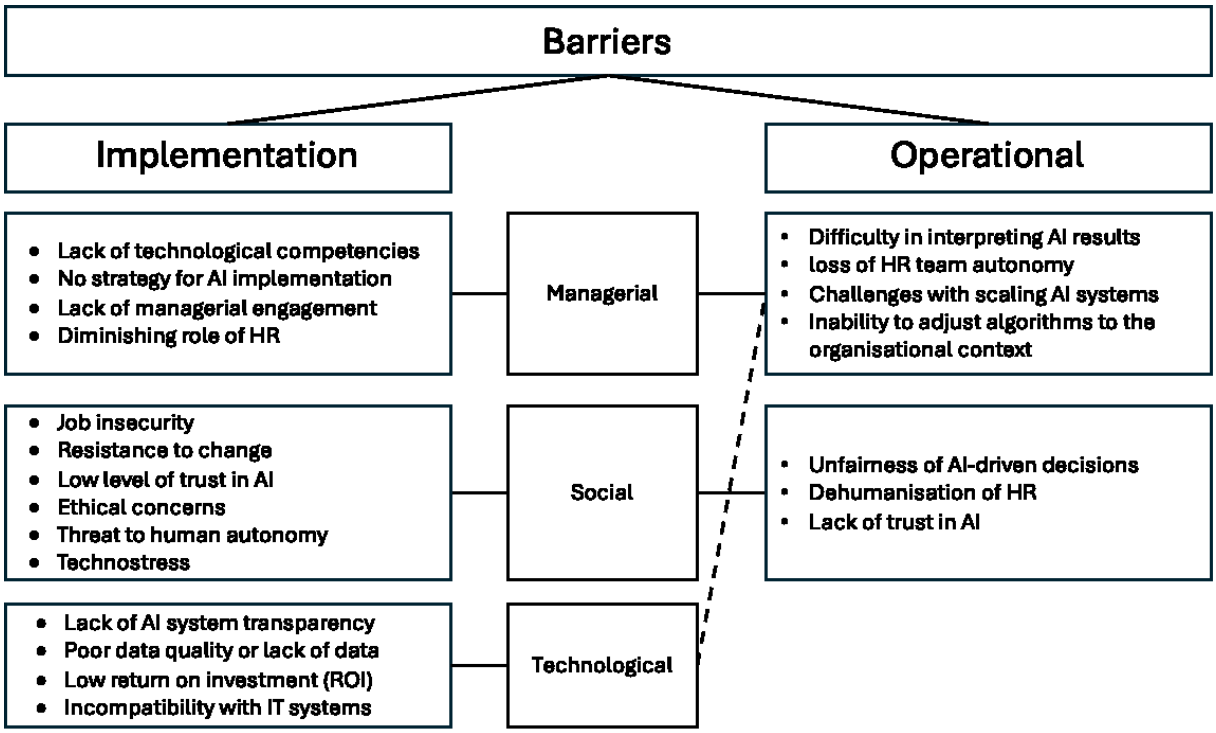

Figure 1. Classification of Implementation and Use Barriers of AI in HRM.

Source: Own study.

These barriers occur during the planning and implementation stages and during the day-to-day use of AI applications, indicating the complex and dynamic nature of digital transformation processes in HRM. Key obstacles include a lack of technological and analytical competencies, poor data quality, employee resistance to change, and low trust in algorithmic decision-making. Therefore, the integration of AI into HR practices requires not only technical adaptation but also a fundamental shift in organizational culture and in the way people management is conceptualized.

These findings also have important implications when viewed through the lens of strategic HRM frameworks. For instance, several of the identified barriers—such as lack of managerial engagement or an unclear strategic vision—directly hinder the HR function's ability to act as a Strategic Partner or Change Agent, as described in Ulrich's model. Similarly, operational challenges such as overreliance on AI systems or limited interpretability of algorithmic outputs may undermine the credibility of HR and its role as an advocate for employees. Integrating AI into HRM, therefore, should not be regarded solely as a technical upgrade but as a strategic transformation aligned with the core values and roles of the HR function.

Given these considerations, it is essential to formulate practical recommendations to support organizations in effectively integrating AI into HRM. First, it is necessary to develop digital and analytical competencies among HR professionals and managers. Previous research indicates that limited technological literacy and a lack of algorithmic thinking are among the primary sources of resistance and misinterpretation of AI-driven systems. Equally important is building trust in AI technologies, which can be achieved through the use of transparent and explainable models that allow users to understand how algorithms function and on what basis they generate recommendations. Another critical area is data governance. Organizations must establish clear standards for data collection, integration, and quality assurance, including the development of coherent information systems and appropriate control mechanisms. Ethical standards and privacy protection are also fundamental, particularly in relation to sensitive employee data. This requires compliance with legal regulations and transparent communication about the purpose and methods of data processing. Finally, the active involvement of stakeholders in the implementation process is vital. Engaging HR professionals, managers, and employees in the design and evaluation of AI applications fosters acceptance, reduces uncertainty, and reinforces a sense of shared responsibility for the success of digital transformation initiatives. Collectively, these actions create the foundation for the responsible and effective use of AI in managing human capital.

From the perspective of advancing the field of HRM, there is a clear need for more in-depth research on the impact of AI on the HR function, both theoretically and empirically. Current literature lacks well-developed conceptual frameworks for understanding how AI integration transforms job roles, the professional identity of HR practitioners, and interpersonal dynamics within organizations. Interdisciplinary research that bridges technological perspectives with insights from the social sciences is needed to capture the systemic nature of these transformations. Empirical studies—both qualitative and quantitative—should also be conducted to examine specific cases of AI implementation, its organizational outcomes, and employee responses. Case studies and longitudinal research are particularly valuable for identifying measurable effects and long-term consequences of AI adoption in HRM. This research agenda should further include exploration of the social and ethical implications of AI use in HR, including algorithmic bias, the marginalization of certain employee groups, and the opacity of decision-making processes. These concerns underscore the need for robust theoretical and practical frameworks to assess fairness, accountability, and transparency in AI applications. Future studies should also address sectoral and cultural comparisons, as there is limited knowledge about how barriers and enablers vary between public and private sectors or across geographic contexts such as Europe, Asia, and developing countries. Another important area for exploration is the long-term impact of AI on the HR function itself—specifically, the evolution of organizational processes and the emergence of new competency expectations for HR professionals. It is also essential to assess the effectiveness of managerial interventions, including training programs, communication strategies, and structural

adjustments, in enhancing organizational readiness for AI adoption. Finally, given the expanding role of AI in HR decision-making, the academic community should contribute actively to the development of consistent ethical and regulatory standards governing AI use in HRM. Addressing these research directions can significantly support the sustainable, informed, and responsible development of HRM practices in the age of AI.

This article is based on a selected set of empirical and theoretical studies published between 2020 and 2024. The study's limitations primarily concern potential selection bias, including the predominance of English-language literature and the heterogeneity of the analyzed materials, which include case studies, quantitative research, and conceptual papers. Additionally, the diversity of research contexts—encompassing various geographic, sectoral, and organizational settings—may affect the comparability of findings. Furthermore, the literature reveals significant gaps, particularly the underrepresentation of research from developing countries and underexplored areas such as public administration and nonprofit organizations. As such, the findings presented herein should be interpreted as a synthetic overview of the current state of knowledge, identifying key trends and challenges rather than providing an exhaustive or definitive account of the topic.

References

1. Angelova, M., Stoyanova, T., Stoyanov, P. (2023). Improving HR management in innovative business organisations through digitalisation and ICT. *Entrepreneurship and Sustainability Issues, 11(2),* 403-418. https://doi.org/10.9770/jesi.2023.11.2(27)
2. Ardichvili, A. (2022). The impact of artificial intelligence on expertise development: Implications for HRD. *Advances in Developing Human Resources, 24(2),* 78-98. https://doi.org/10.1177/15234223221077304
3. Attride-Stirling, J. (2001). Thematic networks: An analytic tool for qualitative research. *Qualitative Research, 1(3),* 385-405. https://doi.org/10.1177/146879410100100307
4. Bazrkar, A., Moradzad, M., Shayegan, S. (2024). The use of artificial intelligence in employee recruitment in the furniture industry of Iran according to the role of contextual factors. *Studia Universitatis „Vasile Goldis" Arad – Economics Series, 34(2),* 86-109. https://doi.org/10.2478/sues-2024-0009
5. Bhatt, P. (2023). AI adoption in the hiring process – Important criteria and extent of AI adoption. *Foresight, 25(1),* 144-163. https://doi.org/10.1108/FS-07-2021-0144
6. Bohmer, N., Schinnenburg, H. (2023). Critical exploration of AI-driven HRM to build up organisational capabilities. *Employee Relations, 45(5),* 1057-1082. https://doi.org/10.1108/ER-04-2022-0202

7. Cao, T.M., Nguyen, L.T.V. (2024). Factors affecting artificial intelligence (AI) adoption in the talent acquisition process: The case of Vietnam's medium-sized firms. *Journal of Asia Business Studies*. https://doi.org/10.1108/JABS-08-2024-0444
8. Chowdhury, S., Joel-Edgar, S., Dey, P., Bhattacharya, S., Kharlamov, A. (2023). Embedding transparency in artificial intelligence machine learning models: Managerial implications on predicting and explaining employee turnover. *International Journal of Human Resource Management, 34(14),* 2732-2764. https://doi.org/10.1080/09585192.2022.2066981
9. Clarke, V., Braun, V. (2016). Thematic analysis. *The Journal of Positive Psychology, 12(3),* 297-298. https://doi.org/10.1080/17439760.2016.1262613
10. Conte, F., Siano, A. (2023). Data-driven human resource and data-driven talent management in internal and recruitment communication strategies: An empirical survey on Italian firms and insights for European context. *Corporate Communications: An International Journal, 28(4),* 618-637. https://doi.org/10.1108/CCIJ-02-2022-0012
11. Cubric, M. (2020). Drivers, barriers and social considerations for AI adoption in business and management: A tertiary study. *Technology in Society, 62,* 101257. https://doi.org/10.1016/j.techsoc.2020.101257
12. Czakon, W. (Ed.). (2015). *Podstawy metodologii badań w naukach o zarządzaniu* (3rd ed.). Wolters Kluwer.
13. Destriani, R., Adhitama, R.Y., Sensuse, D.I., Hidayat, D.S., Purwaningsih, E.H. (2024). Challenges and technology trends in implementing a human resource management system: A systematic literature review. *Journal of Information Systems Engineering and Business Intelligence, 10(3),* 355-367. https://doi.org/10.20473/jisebi.10.3.355-367
14. Dutta, D., Kannan Poyil, A. (2023). The machine/human agentic impact on practices in learning and development: A study across MSME, NGO and MNC organisations. *Personnel Review*. https://doi.org/10.1108/PR-09-2022-0658
15. Dutta, D., Mishra, S.K. (2025). Artificial intelligence-based virtual assistant and employee engagement: An empirical investigation. *Personnel Review, 54(3),* 913-934. https://doi.org/10.1108/PR-03-2023-0263
16. Faqihi, A., Miah, S. (2023). Artificial intelligence-driven talent management system: Exploring the risks and options for constructing a theoretical foundation. *Journal of Risk and Financial Management, 16(1),* 31. https://doi.org/10.3390/jrfm16010031
17. Gélinas, D., Sadreddin, A., Vahidov, R. (2022). Artificial intelligence in human resources management: A review and research agenda. *Pacific Asia Journal of the Association for Information Systems, 14(6).* https://doi.org/10.17705/1pais.14601
18. Islam, M.A., Aldaihani, F.M.F., Saatchi, S.G. (2023). Artificial intelligence adoption among human resource professionals: Does market turbulence play a role? *Global Business and Organizational Excellence, 42,* 59-74. https://doi.org/10.1002/joe.22226

19. Korzynski, P., Mazurek, G., Altmann, A., Ejdys, J., Kazlauskaite, R., Paliszkiewicz, J., Wach, K., Ziemba, E. (2023). Generative artificial intelligence as a new context for management theories: Analysis of ChatGPT. *Central European Management Journal, 31(1),* 3-13. https://doi.org/10.1108/CEMJ-02-2023-0091
20. Kshetri, N. (2021). Evolving uses of artificial intelligence in human resource management in emerging economies in the global South: Some preliminary evidence. *Management Research Review, 44(7),* 970-990. https://doi.org/10.1108/MRR-03-2020-0168
21. Li, P., Bastone, A., Mohamad, T.A., Schiavone, F. (2023). How does artificial intelligence impact human resources performance: Evidence from a healthcare institution in the United Arab Emirates. *Journal of Innovation & Knowledge, 8*(2). https://doi.org/10.1016/j.jik.2023.100340
22. Malin, C., Kupfer, C., Fleiß, J., Kubicek, B., Thalmann, S. (2023). In the AI of the beholder: A qualitative study of HR professionals' beliefs about AI-based chatbots and decision support in candidate pre-selection. *Administrative Sciences, 13*(11), 231. https://doi.org/10.3390/admsci13110231
23. Marler, J.H. (2024). Artificial intelligence, algorithms, and compensation strategy: Challenges and opportunities. *Organizational Dynamics, 53*(1). https://doi.org/10.1016/j.orgdyn.2024.101039
24. McCarthy, J., Minsky, M.L., Rochester, N., Shannon, C.E. (1955). *The proposal for the Dartmouth Summer Research Project on Artificial Intelligence.* http://www-formal.stanford.edu/jmc/history/dartmouth.html
25. Murugesan, U., Subramanian, P., Srivastava, S., Dwivedi, A. (2023). A study of artificial intelligence impacts on human resource digitalization in Industry 4.0. *Decision Analytics Journal, 7*. https://doi.org/10.1016/j.dajour.2023.100249
26. Oswald, F.L., Behrend, T.S., Putka, D.J., Sinar, E. (2020). Big data in industrial-organizational psychology and human resource management: Forward progress for organizational research and practice. *Annual Review of Organizational Psychology and Organizational Behavior, 7*(1), 505-533. https://doi.org/10.1146/annurev-orgpsych-032117-104553
27. Paramita, D., Okwir, S., Nuur, C. (2024). Artificial intelligence in talent acquisition: Exploring organisational and operational dimensions. *International Journal of Organizational Analysis, 32*(11), 108-131. https://doi.org/10.1108/IJOA-09-2023-3992
28. Qamar, Y., Agrawal, R., Samad, T., Jabbour, C. (2021). When technology meets people: The interplay of artificial intelligence and human resource management. *Journal of Enterprise Information Management, 34*(5), 1339-1370. https://doi.org/10.1108/JEIM-11-2020-0436
29. Rukadikar, A., Khandelwal, K. (2024). Navigating change: A qualitative exploration of chatbot adoption in recruitment. *Cogent Business & Management, 11*(1). https://doi.org/10.1080/23311975.2024.2345759

30. Shaw, J., Rudzicz, F., Jamieson, T., Goldfarb, A. (2019). Artificial intelligence and the implementation challenge. *Journal of Medical Internet Research, 21*(7). https://doi.org/10.2196/13659
31. Suseno, Y., Chang, C., Hudik, M., Fang, E.S. (2021). Beliefs, anxiety and change readiness for artificial intelligence adoption among human resource managers: The moderating role of high-performance work systems. *The International Journal of Human Resource Management, 33*(6), 1209-1236. https://doi.org/10.1080/09585192.2021.1931408
32. Verma, S., Rana, N., Meher, J.R. (2023). Identifying the enablers of HR digitalisation and HR analytics using ISM and MICMAC analysis. *International Journal of Organizational Analysis*. https://doi.org/10.1108/IJOA-01-2023-3611
33. Yadav, S., Kapoor, S. (2024). Retraction Note: Adopting artificial intelligence (AI) for employee recruitment: The influence of contextual factors. *International Journal of System Assurance Engineering and Management.* https://doi.org/10.1007/s13198-024-02562-x
34. Yue, H. (2024). Study of enterprise human resource management strategy based on hybrid deep learning models. *Journal of Logistics, Informatics and Service Science, 11*(2), 419-432. https://doi.org/10.33168/JLISS.2024.0226

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SECURITY AWARENESS REGARDING ONLINE AND MOBILE E-BANKING COMMUNICATION CHANNELS AMONG STUDENTS IN POLAND IN 2024

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Purpose: This article examines students' awareness of digital security in electronic banking. The study takes into account the following areas related to the issue: the general awareness of computer system security and the level of cybersecurity threat awareness, particularly in the context of understanding and familiarity with fundamental concepts in the use of electronic banking. In addition, the research assessed the participants' level of experience with electronic banking.
Design/methodology/approach: The survey was conducted in 2023 using the CAWI method and included more than 310 students. An analysis of the results was carried out, followed by a discussion of the findings, and concise conclusions were drawn in relation to the specific areas examined in the study.
Findings: The research revealed that respondents are aware of the risks associated with using electronic banking, tend to associate the concept of security primarily with protecting personal data, and express a need for more proactive cybersecurity education efforts from banks and key institutions in the Polish financial sector.
Research limitations/implications: The main limitation of the study, as it was conducted exclusively within an academic environment. Another limitation is related to the lack of exploration of respondents' attitudes toward the latest advancements in this field.
Practical implications: These suggestions may also serve as a valuable resource for practitioners in the financial sector seeking to develop initiatives aimed at enhancing cybersecurity awareness among their clients.
Social implications: Recommendations were formulated that may be useful for scholars interested in exploring the recognition of computer security issues in the context of electronic banking.
Originality/value: The original contribution of the article lies in presenting the current attitudes of students toward the issue of security in individual banking operations.
Keywords: IT security; electronic banking; cybersecurity; security of banking operations; security of electronic banking.
Category of the paper: Research paper.

1. Introduction

The use of information technologies, particularly those intended for widespread public use, has become a common phenomenon and will undoubtedly continue to expand. However, as this trend progresses, the number of crimes committed with the use of such technologies, i.e., cybercrime, is also increasing. On the other hand, users of technology, particularly those utilizing public networks such as the Internet, expect that the services provided through these means will ensure their security. The provider's responsibility is to secure products and services provided using the network. Still, they will be helpless if users (customers) do not follow at least the basic security principles when using information technology. The Internet, website services, and mobile applications are highly vulnerable to cybercrime. In e-banking, this will include online banking services and bank applications installed on mobile devices. They are also the primary channels for customers to communicate with their banks. Therefore, the study aimed to examine the extent to which students, who are one of the social groups most open to adopting new technologies, understand the concept of security in the context of internet communication channels and mobile electronic banking. This study complements the author's long-standing analysis of the e-banking market and public perceptions of new technologies.

The growing threat emerging from the digital space of the public Internet is clearly illustrated by recent statistics. According to *Security Magazine*, there are more than 2200 attacks daily, equating to almost one cyberattack every 39 seconds. Each year, on average, about 2220 cyberattacks are registered each day, equivalent to more than 800,000 attacks per year. According to Cobalt (Top Cybersecurity Statistics for 2024 | Cobalt, n.d.), nearly 95% of all digital breaches are caused by human error. Europe experienced 85% of all hacking attacks observed in 2023, followed by North America at 7% and the Middle East at 3% (Poireault, 2023). Similar cybercrime statistics can be observed in Poland. In 2023, the number of companies that recorded at least one cybercrime incident increased by eight percentage points to 66%. The proportion of companies reporting 30 or more security incidents increased by 6 percentage points - from 5% in 2019 to 11% in 2023. At the same time, the share of companies that reported no attacks at all declined by 14 percentage points, from 46% in 2019 to 32% in 2023. According to 70% of the organizations surveyed in 2023, organized criminal groups are perceived as a significant source of threats (Kurek et al., 2024). Among the research data cited, particular attention should be given to those related to organizations operating within the financial sector in Poland. According to the latest *Check Point Threat Intelligence* data, Polish financial institutions find themselves in a particularly challenging situation. With an average of 1728 attacks per week targeting a single organization, Poland significantly surpasses neighboring countries in terms of the scale of cyber threats: the Czech Republic, 1211; Austria, 993 or Hungary, 780. What is also worrying is that the number even exceeds the global average of 1689 attacks (Ataki Hakerskie Na Banki…, n.d.).

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To gain a proper understanding of the concept of security, it is important to refer to a definition of organizational security. The definition of Shockley-Zabalak, Ellis and Winograd states that trust is "The willingness of an organization, based on its culture and the way it communicates when operating and in its relationships with others, to be responsive and cooperative, assuming the belief that the individual, group or organization is competent, open, honest, interested and reliable, and that it identifies with common goals, norms and values" (Schwabe, 2023). This definition highlights several key elements, including the organization's intent and actions aimed at cooperating with external entities (including clients) to achieve

a state of security for itself. Security within an organization directly contributes to the level of trust it earns from its clients. In today's world, where public networks such as the Internet have become the primary channels of communication between organizations and their clients, it is important to address the issue of cybersecurity. It encompasses the protection of tools, systems, processes, concepts, methods and strategies to protect assets in cyberspace from unauthorized access and loss of information, leading to the preservation of the integrity, confidentiality and availability of resources (Taherdoost, 2022). The definition indicates achieving a state of security regarding an organization's ICT resources. Electronic banking is a special area of an organization's IT systems, including the organization itself and its customers. A secure electronic banking system can be defined as one in which the six attributes of confidentiality, integrity, authenticity, non-repudiation, availability and reliability have reached an acceptable level for the bank and its customers (Zalewska-Bochenko, Siemieniuk, 2010; Korzeń, 2007). Achieving such a state requires not only strong commitment from the organization itself, namely, the bank, but also relies significantly on clients' awareness of potential threats and their corresponding behaviors. In the case of large organizations such as banks, a kind of imbalance of knowledge about cyber threats enters the picture. It is evident that banks and their clients face different types of threats; however, it should be recognized that both parties share the responsibility for maintaining the security of the bank's information systems, and, consequently, their own security as well.

Effective cyber-security of electronic banking requires the integration of advanced technical defense mechanisms with tailored educational strategies for its users that take into account awareness gaps, cognitive biases and cultural factors. In the literature, the phenomenon of cybersecurity in the field of electronic banking is typically examined within several contexts, including strategic, technical, educational, risk factor analysis and regulatory perspectives.

In the strategic context, special attention was paid to a comprehensive analysis of cybercrime incidents, assessing the financial impact of cyberattacks, evaluating the effectiveness of the existing cybersecurity framework and making strategic recommendations to strengthen cybersecurity measures.(Oyewole et al., 2024) Another important concept was recognizing the digital technologies being implemented in the banking industry and their impact on the growth of digital fraud, with a particular focus on online banking fraud.(Ahmad et al., 2024) In the technical context, attention was paid to the security measures used. These include: authentication methods (multi-component authentication (Karim et al., 2024; Malinka et al., 2022), biometrics). It was pointed out that the methods improve security, but require user acceptance and trust (Hajjisaaid, Ahmed, 2020). The aspect of utilizing artificial intelligence and machine learning has also been taken into consideration. It was pointed out that they support the detection of anomalies and improve the accuracy of predictive analytics. It was shown that their use improves the effectiveness of combating advanced attacks, such as: polymorphic malware or fraud (Deshmukh, 2024). In the area of mobile banking, there has been a noted increase in attacks targeting mobile platforms, highlighting the need for secure API interfaces,

the use of application sandboxing and user education on threats specific to mobile devices (Kangapi, Chindenga, 2022). In the educational context, studies have shown gaps in awareness of cybersecurity principles among vulnerable populations (A Study on Customer Awareness…, 2025). In the context of the behavioral approach, it has been indicated that gamification and active learning are preferred over traditional methods of merely informing users about precautionary behaviors. The above mentioned approaches are characterized by higher effectiveness in the long-term formation of safe habits (Prevention Of Cyber Frauds…, n.d.). Studies have pointed to the importance of promoting a safety-conscious culture through institutional policies and education in the regulatory and risk factor context. These approaches play a crucial role in reducing user-induced security breaches. The literature on the subject also examined how new regulations (e.g., PSD2) strengthen the implementation of secure multi-factor authentication practices (Malinka et al., 2022; A Regulatory Framework…, 2024).

As previously noted, most literature sources on cybersecurity in electronic banking concentrate on areas such as strategy, technology, user education, risk assessment or regulatory frameworks. However, relatively few studies specifically explore users' perceptions of cybersecurity in the context of online and mobile banking.

This article aimed to assess the level of students' understanding of computer system security, their awareness of common cybersecurity threats and their prior experiences in this field. The research, based on survey data and subsequent analysis, focuses specifically on students' perceptions of cybersecurity in electronic banking, with particular attention paid to two access channels: online and mobile banking. The analyses will help determine the extent of students' knowledge regarding cybersecurity when using online and mobile banking services.

In realizing the article's purpose, the following research questions were adopted: Which threats in using computer systems are recognized by their users? How do the respondents understand the issue of cybersecurity? How do the respondents perceive the security issue in their electronic (online and mobile) banking? How do respondents assess the banks' activities in raising respondents' knowledge of the risks of using electronic banking?

The article is divided into five parts: introduction, literature review, research methodology, discussion of results and conclusions. The introduction provides an overview of the research topic and outlines the context for the study. The second section reviews the current state of research on individual users' perceptions of computer security in electronic banking. It also highlights areas related to user perceptions of cybersecurity in electronic banking that have not yet been sufficiently explored. The following section includes a presentation of the research procedure adopted and the research sample characteristics. The fourth section presents the research results and compares them with findings from the existing literature on the subject. The article's final section presents the conclusions drawn from the analysis and discussion, outlines the study's limitations and suggests directions for future research.

This article is part of the author's ongoing, cyclical research on how consumers perceive changes in behavior related to e-banking phenomena (Chmielarz, Zborowski, 2024; Chmielarz et al., 2021).

2. Perception of cybersecurity

The issue of e-banking security is typically analyzed across several broad dimensions, including strategic, technical, educational, risk assessment and regulatory aspects. However, relatively few studies focus on how bank customers perceive security when conducting online and mobile banking transactions.

From a strategic perspective, Oyewole et al. (Oyewole et al., 2024), based on their research, emphasized that the banking sector should adopt a holistic approach to cybersecurity, involving coordinated investments in technology, user education and inter-organizational collaboration. Further recommendations include the integration of Big Data analytics, artificial intelligence and continuous risk assessment to respond to diverse and emerging forms of cyber threats effectively. The authors pointed to the need for a more substantial commitment by banking institutions to strengthen cybersecurity to protect financial assets and maintain customer trust. Dawodu et al. (Cybersecurity Risk Assessment In Banking, 2023) emphasize the importance of continuous monitoring and incident response planning as part of banks' cybersecurity. The authors point out that these measures are essential for detecting and responding to cyber threats in a timely manner. In the technical context, Priyadarshini and Geetha (E-Banking, n.d.) discussed experimental models for improving online banking security, and Mohammed and Mohammed (Mohammed, Mohammed, 2024) proposed a Role-Based Access Control (RBAC) model for enhancing authentication security in online banking. These studies point to the growing role of technological innovation in securing financial transactions. The banking sector is increasingly becoming a target for cybercriminals using advanced techniques to breach security. Dawodu et al. (Cybersecurity Risk Assessment In Banking, 2023) emphasize the critical role of cybersecurity risk assessment in banking, pointing to the need for banks to identify, analyze and assess threats. This process is essential for implementing controls to mitigate risks and comply with regulations. The study underscores the importance of adopting quantitative and qualitative risk assessment approaches, including threat modeling and scenario analysis. Garba, Kaur and Ibrahim (Garba et al., 2023) studied the human factors influencing cybersecurity culture among online banking users in Nigeria. Their research underscores the importance of cybersecurity awareness, policy and education in promoting the right attitudes and behaviors to enhance cybersecurity. The study reveals a clear knowledge gap in cybersecurity and highlights the under-researched influence of social norms and interpersonal trust in shaping cybersecurity culture. In one of the publications covering institutional awareness and risk management, Tiwari et al. (A Survey of Cybersecurity Threats…, n.d.)

presented the results of the study in which they surveyed 750 financial professionals in India. The survey identified critical gaps in the effectiveness of protection measures against cyber threats. They also identified a need for greater emphasis on training programs. Dongol and Chatterjee (Dongol, Chatterjee, 2019) examined cybersecurity practices at Nepalese banking institutions, finding weaknesses in security implementation. Arora et al. (Arora et al., 2022) analyzed cybersecurity case studies in both developing and developed countries, categorizing security threats and methodologies. Ahmad et al. (Ahmad et al., 2024) analyzed the relationship between digital banking technologies and the rise of fraud threats such as phishing and denial-of-service attacks. Cele and Kwenda (Cele, Kwenda, 2024) reviewed the literature using 58 previous studies to identify cybersecurity threats hindering the adoption of digital banking worldwide. The authors highlighted that phishing, malware and identity theft are major obstacles to the spread of e-banking. Regulatory perspectives have a significant impact on shaping global cybersecurity practices. Gupta et al. (Gupta et al., 1 C.E.) analyzed the U.S. Federal Financial Institutions Examination Council (FFIEC) guidelines for electronic banking authentication. The researchers discussed their implications for the security policies of financial institutions.

Within the context of this article, special attention is devoted to studies examining customers' perspectives on cybersecurity in both online and mobile banking operations. Alghazo et al. (Alghazo et al., 2017) conducted an extensive survey of 1044 online banking users in Saudi Arabia, Pakistan and India. The survey revealed gaps between users' cybersecurity practices and institutional expectations. Similarly, Matlala (Behavioural Insights…, 2024) used structural equation modeling (SEM) to assess the behavioral determinants of cybersecurity intentions among 338 South African e-banking customers. Sanusi (Sanusi, 2015) surveyed 237 Nigerian banking users, reporting high awareness of basic security measures. The author of the study considered it essential to place greater emphasis on educating users about safe practices in the use of electronic banking services. The cited studies underscore the role of user awareness in maintaining a high level of cybersecurity, but it is essential to keep in mind their regional nature. Naturally, this does not diminish their significance within the broader scope of research on electronic banking security.

The research presented in the subsequent sections of the article contributes to the broader international academic literature by offering insights into the level of awareness regarding security issues in the use of computer systems for electronic banking, as observed within a selected research group. The study adopted the following contexts: understanding of the issue of security of computer systems, awareness of the risks specific to cybercrime, learning about the participants' previous experience of cybercrime in the use of electronic banking and indications of expectations of initiatives on the part of banks in the area of cybersecurity. The research focused on analyzing the mentioned contexts in customer communication with banks in online and mobile banking channels. It is important to note that the study is regional and limited to the academic community.

3. Research methodology

3.1. Characteristics research methodology and survey questionnaire

In reference to the author's previous analyses and research (Zborowski, Chmielarz, 2023, 2024) on the perception of new technologies, a research procedure was developed, which generally includes: literature research, creation of a research survey, use of the CAWI method, calculation and interpretation of the obtained results.

The individual stages of the adopted research procedure are as follows:

- conducting literature review and consulting with experts on the theory of computer systems security and awareness of the perception of this phenomenon in society, with a particular focus on students,
- preparing the first version of the survey questionnaire, based on the above considerations, combined with the author's own expertise and observations of the studied phenomenon, stemming from his extensive experience cooperating with IT teams,
- verifying the clarity and relevance of the survey questions through a pilot study conducted on a randomly selected group of respondents,
- developing the final version of the survey questionnaire and selecting student groups at random for the implementation of the study,
- sharing the link to the survey questionnaire (using the CAWI method – Computer-Assisted Web Interview) with the previously selected student groups,
- collecting the survey questionnaires, presentation of their results, subsequent analysis and discussion of the data,
- drawing conclusions and presenting potential directions for further research.

The analysis of theoretical material, combined with consultations with experts in the studied field, enabled the formulation of requirements for a survey on the perception of computer system security, with a particular focus on electronic banking. It was assumed that the questionnaire, in addition to assessing participants' perceptions of key concepts, should also serve as an informative tool, increasing respondents' awareness of potential threats present online. This approach represents a specific response to the issues outlined in the introduction of the article. In addition, the survey draws respondents' attention to the key risks that may occur in using electronic banking in the area of cybercrime. The survey was aimed at students of management, who are expected to assume managerial roles upon graduation and will have a tangible impact on shaping the attitude of their organizations both in terms of the awareness of implementing security policies and also, among other things, communicating to clients that their security also depends on their own actions.

Taking the above requirements into account, the first version of the survey consisted of a series of sequential questions: frequency of Internet use; the type of e-banking preferred when communicating with the bank; understanding of the definition of cyber-security and its main components; awareness of the risks that occur when using a computer network; recognition of the most common types of attacks on the network and experience with them; awareness of the sources of threats on the Internet and the intentions of the authors of the attacks; the characteristics of application-level threats; the respondent's personal experiences with cybercriminal activities; their assessment of personal sense of security in electronic banking; and educational initiatives undertaken both by banks and by institutions acting in the interest of the security of the banking sector and its clients.

Appropriate revisions were made after consultations with students (a pilot group of twenty randomly selected individuals) regarding their understanding of the survey questions and the clarity of the provided answer options. The corrections to the survey form consisted of removing two questions and adding one assessing the respondent's level of trust in the bank's computer systems. The final version of the survey included 26 content questions and five questions related to respondents' demographic characteristics.

The survey was conducted from May to June 2023 among second-year students of the Finance Management and Accounting program at the Faculty of Management, University of Warsaw. The results were collected by the CAWI method using LimeSurvey software. The survey questionnaire was hosted on the Faculty of Management's servers. Upon completion of the study, the results were processed in MS Excel using pivot tables. Subsequently, relevant charts were prepared to illustrate the findings.

3.2. Characteristics of the research sample

The data were collected and categorized based on gender, age, level and field of education, place of residence as well as professional status and financial situation. The characteristics of the research sample are shown in Table 1.

Table 1.
Basic characteristics of the sample

Characteristics	Percentage share
Gender	
woman	75.81%
man	24.19%
Age	
19-24	96.77%
25-34	2.90%
35-55	0.32%
Education	
Bachelor's degree	78.71%
incomplete higher education	12.90%
secondary	6.77%
higher education	1.61%

Cont. table 1.

Place of residence	
town of 21,0000-50,000 residents	4.84%
city of 51,000-200,000 residents	4.84%
town of up to 20,000 residents	10.00%
city with over 200,000 residents	16.45%
village	63.87%
Field of study (present or completed)	
social sciences, including management, psychology, sociology, economics, pedagogy, administration, law	75.81%
other	16.13%
science, including mathematics, computer science, physics, chemistry	8.06%
Financial situation	
very good (I can afford everything I need, and I can save some money)	20.00%
good (I am not complaining, but it could be better)	51.61%
satisfactory (I can still make ends meet)	2.58%
I am a student, I am not financially independent	8.71%
average (I have enough money to live frugally)	17.10%
Professional status	
I am a student	43.87%
I work on a casual basis (on a contract for work/contract)	31.29%
I work on a full-time or part-time employment contract	17.10%
other	7.10%
I run my own business	0.65%

Source: own work.

An analysis of the data presented in Table 1 indicates that the research sample was characterized by a relatively high degree of diversity. However, it encompassed a total of over 310 individuals who are among the most active participants in the labor market in terms of education and age (Batorski, 2015).

In the survey sample analyzed (Table 2), the standard deviation values are highest for age at 54.96%, and lowest for work situation at 13.91%.

Table 2.
Statistical analysis of input data from the research sample

Characteristics	Percentage share
Age	
Variance	30.20%
Standard deviation	54.96%
Education	
Variance	11.02%
Standard deviation	33.19%
Place of residence	
Variance	6.24%
Standard deviation	24.98%
Field of study (present or completed)	
Variance	13.69%
Standard deviation	37.00%
Financial situation	
Variance	3.60%
Standard deviation	18.97%
Professional status	
Variance	1.94%
Standard deviation	13.91%

Source: own work.

Analyzing the data in Table 2, the greatest variation occurred in terms of the age of the respondents, with a variance of 30.20% and a standard deviation of 54.96%. Despite the high values of both measures of dispersion in the data, the survey was conducted on a relatively homogeneous group of students from one department in the second year of study. The other measures can be considered low, highlighting the homogeneity of the group.

4. Discussion

The CAWI survey conducted among students of the Faculty of Management at the University of Warsaw consisted of the following sections: infrastructure of network activities, recognizing the issue of computer system security, cybersecurity threat awareness and experience in using electronic banking.

The first section began with an assessment of the respondent's level of familiarity with Internet technology, followed by an examination of how they use it in their interactions with banking services. This was assessed by examining the frequency of the respondent's use of the Internet and the types of commonly used devices they utilize for this purpose. The use of the Internet in contact with the bank was verified by examining which channels in the area of electronic banking the respondent uses to communicate, whether he considers himself an active user of electronic banking, and which of the devices used for this purpose he considers the most secure.

Out of the available response options: *I am connected to the Internet all the time*, *Several times a day*, *Once a day*, *Several times a week*, *Once a week*, *Several times a month*, *Once a month*, *Never,* 84.84% said they are connected to the Internet all the time, and 15.16% said they access the Internet several times a day. Respondents most frequently accessed the Internet using: a smartphone and a PC (desktop or laptop), 58.39%. The second most frequently selected answer was *Other combination of equipment* (e.g., tablet and PC, desktop and smartphone) 23.87%. The least commonly selected option was *only a smartphone* 17.74%. The results obtained may indicate that when browsing the Internet content, the respondents use multiple devices almost simultaneously. They do not limit themselves to only a specific device.

The most frequently selected response regarding access to the respondent's own resources held at their bank was: *banking app on smartphone* (69.03%), followed by *a website on PC and banking app on smartphone* (20.00%). The remaining answers were a combination of channels: *an app and a website on a smartphone, a website on a PC or a smartphone*, and *a website on a smartphone*, which were selected by less than 6%. Therefore, the variance and standard deviation had high values, respectively: 7.1% and 26.63%. Detailed responses are presented in Figure 1.

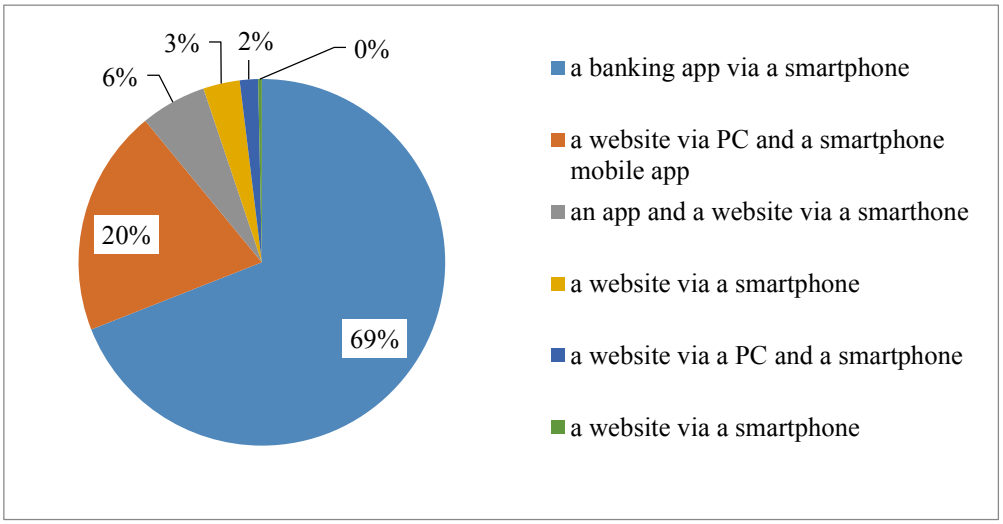

Figure 1. Percentage share of communication media used by respondents to access banking services.
Source: own work.

With regard to self-perception as active users of electronic banking (bank account), respondents most commonly indicated that they access e-banking services a few times a day (38.39%) and a few times a week (36.45%). Electronic banking is used once a month by 20.65% of respondents. The least frequently selected answer was *Once a day* and was selected in 0.65% of cases. For the responses to this question, the variance was 2.7%, and the standard deviation was 16.55%. Detailed responses are presented in Figure 2.

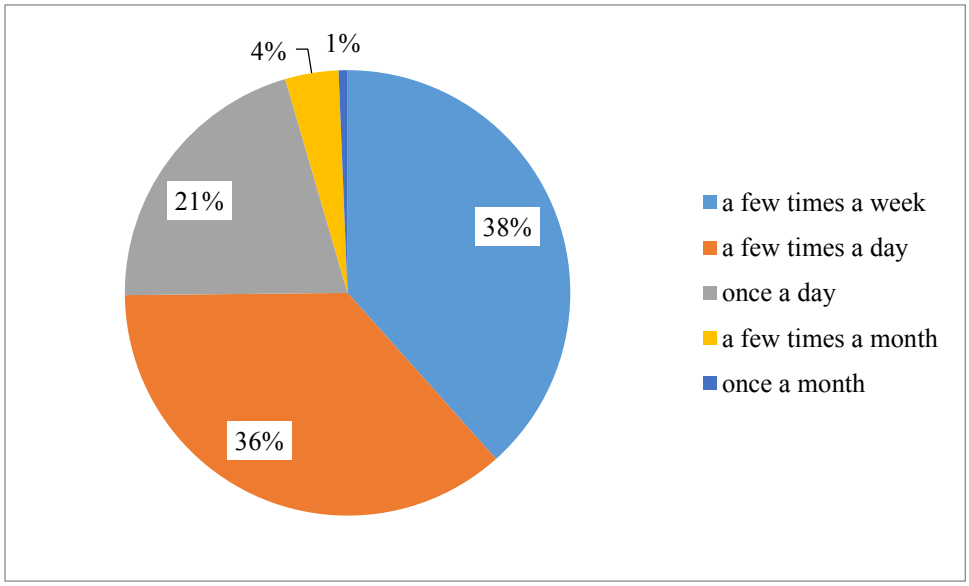

Figure 2. Bank customers' activity as reported by respondents (in %).
Source: own work.

The final question in this section focused on assessing the respondents' subjective perception of the security of specific devices used in interactions with the bank. Of the four possible answers, i.e. *smartphone*, *PC*, *desktop computer*, *tablet*, respondents identified the *smartphone* 42.26% as the safest for using electronic banking. *The PC* was perceived as 8.71 percentage points less secure, with the *desktop computer* rated an additional 9.35 percentage

points lower in terms of security. An interesting observation is that none of the respondents indicated the *tablet* as a secure device, which may suggest that, since they primarily associate it with entertainment and simple tasks, they do not perceive it as safe. Calculations point to a variance of 0.82% and a standard deviation of 9.03%.

Table 3.
Overview of cybersecurity definitions

No.	Definitions (Labels)	Share %
1.	Computer security includes measures and regulations that ensure the confidentiality, integrity and availability of information system assets (goods), including hardware, software, pre-built programs (firmware) and processed, stored and communicated information (Stallings, Brown, 2019)	30.97%
2.	Computer security, cybersecurity or information technology security (IT security) protects computer systems and networks from disclosure of information, theft or damage to hardware, software or electronic data, and disruption or improper performance of services (Informatycznej, 2021)	50.97%
3.	Information systems security relates to the totality of measures designed to secure data stored in a computer so that it cannot be exploited by unauthorized persons or exposed to permanent loss (Wyrębek, 2012)	9.35%
4.	An information system is secure if its users can rely on it and the installed software works according to its specifications (Garfinkel et al., 2003)	1.61%
5.	I see no difference in the definitions.	7.10%

Source: own work.

The next section of the survey, Recognizing the Issue of Computer Systems Security, included a series of questions on aspects such as the definition of cybersecurity, understanding and relevance to the respondent of the components of this issue. The survey presented respondents with four popular definitions of the concept of computer security and added a response of *I don't see a difference in the definitions*. The definitions and the shares of responses are shown in Table 3.

Respondents pointed to the second most accurate definition of cybersecurity, as shown in Table 3 (51% of cases). The second most frequently chosen characteristic of computer security was indicated by 30.97% of respondents. Other options, i.e., the third and fourth, are rated at a similarly low level, 9.35% and 1.61% respectively. The selection of the definitions used in the survey was purposeful. The first two definitions represent a broad approach, encompassing aspects such as devices, software, actions and legal considerations, whereas the third definition focuses more narrowly on actions aimed at preventing data loss. While still correct, the last definition appears to be the least precise. This response structure suggests that respondents are generally aware of issues related to computer system security, demonstrating an understanding of its various aspects.

Table 4.
Components of cybersecurity and their definitions

No.	Cybersecurity characteristics	Percentage share	Definition of cybersecurity features	Percentage share
1.	Data confidentiality	31.72%	Data confidentiality ensures that private or confidential information is not shared or disclosed to unauthorized persons.	34.32%
2.	Data integrity	27.31%	Data integrity (data integrity) ensures that information and programs are subject to change only in specific and authorized ways.	22.72%
3.	Privacy (assurance)	13.33%	Privacy ensures that individuals exercise control or influence over which information concerning them may be collected and stored, and by whom and to whom that information may be disclosed.	23.08%
4.	Responsibility	12.47%	Accountability refers to a security objective that requires an individual's actions to be clearly and uniquely attributable to that individual. This is helpful in achieving: undeniability, containment, fault isolation, violation detection and prevention as well as in corrective actions and legal proceedings after the fact.	1.89%
5.	Authenticity (in the sense of originality)	7.20%	Authenticity (originality). Certainty (conviction, confidence) as to the reliability of a transmission, message or their creator (origin).	2.96%
6.	System integrity	6.45%	System integrity ensures that the system performs the intended functions without interference (is fully operational), unaffected by intentional or unintentional unauthorized manipulation.	8.76%
7.	Availability	1.52%	Availability ensures that systems operate without delay and do not deny services to authorized users.	6.27%
	Variance	1.25%	Variance	1.54%
	Standard deviation	11.20%	Standard deviation	12.43%

Source: own work based on (Stallings, Brown, 2019).

From the listed areas, respondents were asked to select the three they most closely associate with computer security. The most frequently selected answer was *Data Confidentiality, 31.72%, while the least commonly selected answer was Availability,* 1.51%. The detailed response values are presented in Table 4 in columns 2 and 3.

Referring to the values in Table 4, columns 2 and 3, the responses *Data Confidentiality* and *Data Integrity* were selected with similar frequency - in about 30% of cases. The second most frequently selected pair was *Privacy* (13.33%) and *Accountability* (12.47%). The third pair was *Authenticity* (7.20%) and *System Integrity* (6.45%). From the data presented, it can be concluded that the issue of computer security is most often associated primarily with data security. The other elements do not yet exist so strongly in respondents' minds. When definitions were added to each concept, the order of relevance of cybersecurity features changed slightly (columns 4 and 5). *Data Confidentiality* remained the most important concept, with its significance increasing by approximately three percentage points, reaching a value of 34.32%. The second position was already taken by *Privacy* (23.08%). It is worth noting that the definition of this term includes the word *information*, though it is used in a context more characteristic of the term *data*. This confirms the observation made earlier that cybersecurity is

associated with data protection. The third most frequently selected feature was *Data integrity* (22.72%)

The third section of the survey, *Cybersecurity Awareness*, examined recognition of threats present in computer networks, awareness of types of attacks in cyberspace, active and passive threats and sources of both human and software threats.

When surveyed on awareness of key threats, of the three main ones, i.e., *random internal*, *random external* and *intentional threats*, a large majority of respondents indicated the third option. *Intentional threats*, that is, *those carried out deliberately and strategically, typically as part of industrial espionage, vandalism, terrorism, or acts of retaliation, etc.,* were selected in almost 85% of cases. This was followed by *random internal threats* (nearly 12%) and *random external threats* (only about 4%). The answers indicate that respondents perceive the concept of *danger* as having a conscious and premeditated character.

In a question combining both the recognition of the types of attacks in cyberspace and their adverse effect in relation to the resulting use of electronic banking, one can notice three groups of answers. The first: *malware* and *phishing* were selected in 45.39% of cases, the second: *cracking*, *sniffing* and *spoofing* in 45.58%, and the third: *cross-site scripting (XSS)* and *SQL Injection* in 9.04% of cases. A detailed presentation of the significance of the various types of attacks is shown in Figure 3. It is worth mentioning that in the survey form, a definition of each term was presented next to it.

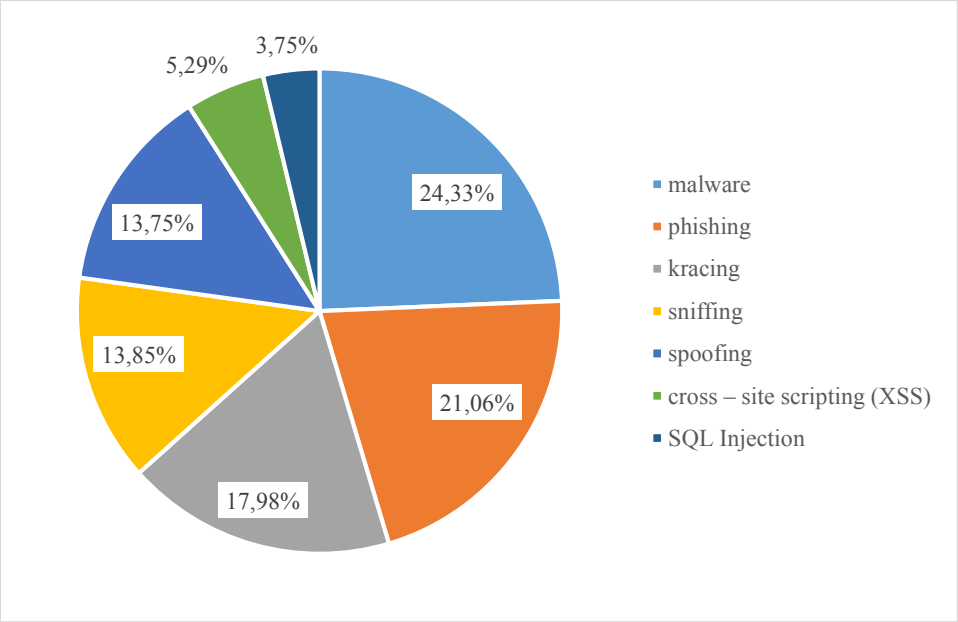

Figure 3. Percentage of responses regarding the significance of different types of cyberattacks.
Source: own work.

The results presented in Figure 3 indicate that respondents identified the following as the most recognizable and dangerous types of attacks: *malware* (24.33%), no less dangerous was *phishing* (21.06%). Slightly less critical is *cracking* (17.98%), *sniffing* and *spoofing* are

practically at the same level around (13%) and *Cross-site scripting (XSS)* and *SQL Injection* (each less than 6%).

One of the main categorizations of network threats is their division into passive and active. Passive threats include eavesdropping, network traffic analysis or revealing emissions. Respondents were asked whether they or their relatives had direct contact with such threats. The majority indicated that they have not encountered these types of problems (41.94%) or do not know if they have had contact with them (32.58%). Contact with this type of threat was mentioned by only 25.48% of respondents. In the case of active threats, understood as the conscious or unconscious actions of bank employees themselves, the majority of respondents (65.81%) indicated that they or their relatives had no contact with this threat. Meanwhile, 25.16% of respondents indicated that they do not know, and fewer than 10% confirmed having encountered such threats. The responses may suggest that the respondents or their close contacts have not encountered passive or active threats. This could indicate either a sense of security or a limited awareness of potential threats.

In understanding the concept of cybersecurity, awareness of the sources of threats is just as important as their classification. In the area of awareness of sources of threats to online and mobile banking, the distribution of variant responses is relatively even, with a variance of 0.03% and a standard deviation of 1.70%. Of the eight sources of threats, respondents were asked to select five. The most frequently indicated responses were: *information contained in banking documentation was previously maintained in paper form; however, with the advancement of computer systems, the vast majority of this information has been transferred to digital systems* (15.23%), and *data held in computer systems can be easily modified by at least two authorized persons: the owner of the data and the system administrator* (15.03%). Detailed data on the responses is provided in Table 5.

Table 5.
Sources of threats to online and mobile banking

Sources of threats to online and mobile banking	Percentage of responses
information contained in banking documentation was previously maintained in paper form; however, with the advancement of computer systems, the vast majority of this information has been transferred to digital systems, where, of course, they can be processed more easily, but are also more susceptible to loss or unauthorized copying (Olczak et al., 2015)	15.23%
data held in computer systems can be easily modified by at least two authorized persons: the data owner and the system administrator (Bandera, Grzywacz, 2016)	15.03%
due to the high costs and the risk associated with low awareness of the importance of data and computer system security, there is a potential risk that IT solutions may be inadequately protected, particularly among managerial staff (Krzysztoszek, 2017)	14.26%
there is also a frequent issue of relying on companies responsible for computer system security that lack proper certification	13.68%
every system, including IT systems, to a greater or lesser degree is always subject to errors, errors in the code, as well as the error of its use (*FTBS 2023*, 2023)	12.06%
the increasing availability of online content has also led to a greater volume and easier access to software that facilitates unauthorized access to organizational computer systems (Siemieniuk, Zalewska-Bochenko, 2017)	11.61%

Cont. table 5.

in the modern economy, the most valuable good has become data and information, the increase in demand for this good causes an increase in the number of actors willing to enter into possession of data by illegal means (Hajduk-Stelmachowicz, Iwan, 2018)	11.03%
any incidents involving unauthorized access to data within a specific institution pose a real threat to its public image. As a result, such institutions often choose not to disclose these occurrences, which in turn may further encourage cybercriminals to attempt gaining access to sensitive data and information (Mazurek, 2023)	7.10%
Variance	0.03%
Standard deviation	1.70%

Source: own work.

Threats to computer system security do not stem solely from malicious software; they can also originate from human actions. In the area of human threats, two answers were indicated at virtually the same level, at about 43% each, as among three possible answers: *the desire to make a profit* and *espionage, which involves stealing valuable information and passing it on to a competing bank*. The response: *the desire to gain publicity by revealing the fact of the intrusion, regardless of whether it was combined with, for example: data theft, changes in the bank's software or not,* was selected significantly less frequently, at a rate of 13.55%. In the area of software-related threats that may have the most adverse effects when using online and mobile banking, where respondents were asked to indicate the three most significant ones, the most frequently selected response was: viruses (29.07%), followed by rats and Trojan horses (22%) each. The least frequently indicated were bacteria and denial of service attacks at about 3% each. It is worth mentioning that the survey form provided respondents with definitions of each type of threat. The detailed distribution of responses is presented in Figure 4.

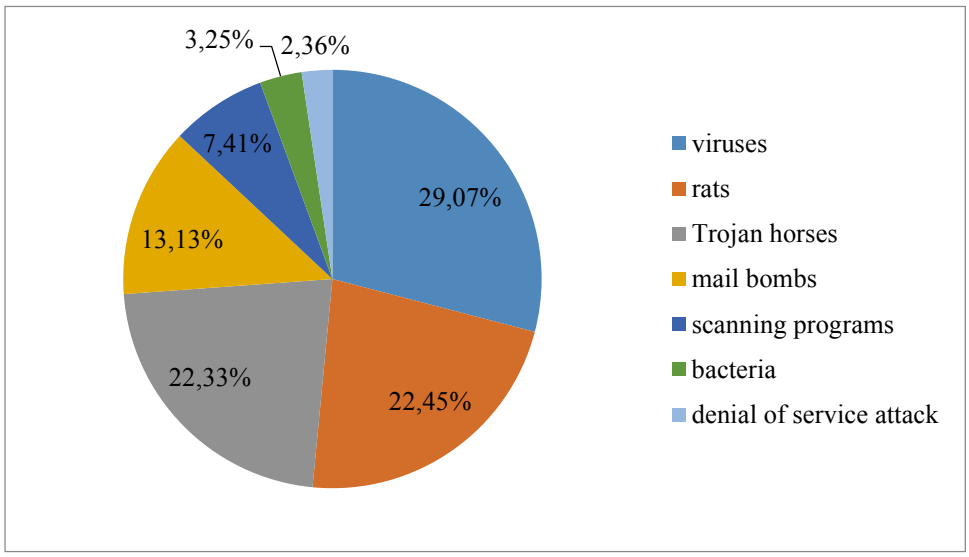

Figure 4. Percentage of responses regarding the relevance of cyber threats.

Source: own work.

Analyzing the data presented in Figure 4, it is worth noting that the selected responses were related to various methods of accessing data. It can be concluded that in the area of electronic banking security (both mobile and online), data breaches are perceived by respondents as the greatest threat, while denial-of-service (DoS) attacks are considered relatively insignificant.

The fourth part of the survey, *Experiences in the use of electronic banking*, examined such aspects as personal experience with cybercrime in the use of electronic banking, perceptions of the security of banking services provided by the respondent's bank, educational activities in the area of computer security undertaken by both the respondent's financial institution and well-known institutions working in the interest of banking sector security and customers.

In the area of the respondent's own experience with the issue of cybercrime, as well as their understanding of the concept, the vast majority of respondents (72.26%) are certain that they have not encountered the problem. 17.74% indicated that they did not know if they had encountered it. Only 1.61% gave the answer that *I don't quite understand the concept*. Less than 10% gave a positive answer. The structure of the responses indicates that respondents perceive the use of electronic banking as safe.

Among those who have experienced cybercrime, the most common responses are: *phishing attempts, theft of personal information, phishing attempts for login credentials, fake text messages, fake bank websites, fake BLIK payment authorization requests* and *phishing attempts for payment card details*.

In terms of overall trust in the security of the respondent's bank's computer systems, the vast majority rated it as *good* (61.61%), while only 20.65% rated it as *very good*. The remaining responses, i.e., *I did not consider it*, *I have no opinion*, *average*, and *poor*, accounted for a total of 17.75% of all responses. Detailed information on the responses provided is presented in Figure 5.

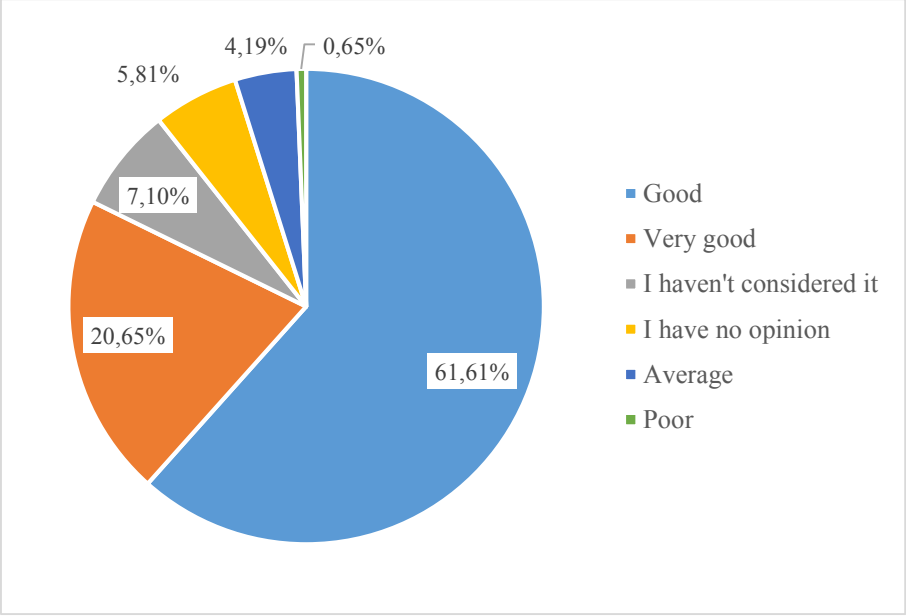

Figure 5. Percentage of responses regarding trust in the security of the respondent's bank's computer systems.

Source: own work.

In assessing the educational activities undertaken by the bank, respondents rated the banks' performance in this area as *good* (33.55%). The answer *very good* was selected by only 12.26% of respondents. The least frequently selected answer was *bad* (0.32%). Detailed information on the evaluation of the initiatives of firm institutions in educational activities is presented in Table 6.

Table 6.
Evaluation of banks' educational behavior regarding cybersecurity

Response	Percentage share
Good	33.55%
Average	20.97%
Very good	12.26%
I have encountered it once, but I don't remember exactly	10.97%
I haven't noticed any	9.35%
I haven't considered it	6.77%
I have no opinion	2.90%
Poor	2.90%
Bad	0.32%
Variance	1.09%
Standard deviation	10.46%

Source: own work.

Referring to the data presented in Table 6, it is worth noting that the responses: *I have encountered it once, but I don't remember exactly*, *I haven't noticed any*, *I haven't considered it*, account for as much as 27.09%. Such a high percentage of responses depicting respondents' uncertainty may suggest that respondents believe banks should engage more strongly in educational activities. These activities would likely raise understanding of the risks involved in using electronic banking.

According to the respondents, institutions such as the Financial Supervision Commission, the Polish Bank Association and the Ministry of Finance should be interested in building awareness of electronic banking security. In the survey, respondents mostly rated the involvement of the aforementioned institutions as *average* (28.71%), while the second most frequently chosen answer was *good* (26.13%). The answer *very good* was selected by only 4.19% of respondents. The remaining responses were negative, with a total of 40.64% of respondents indicating either a lack of knowledge about the subject or no interest in it. The response statistics presented may indicate that respondents expect these types of organizations to undertake a broader commitment to educational activities in the area of computer security.

5. Conclusions

In summary, the results of this study reveal a picture of cybersecurity perception, in which respondents demonstrate great trust in electronic banking systems. In addition, they have not encountered significant threats in cyberspace, but are aware of them. This is evident in the educational needs reported by respondents addressed to institutions supervising the financial market in Poland.

The detailed conclusions include:

- in communication with banks, among all available channels, respondents most frequently chose banking applications installed on smartphones,
- respondents used e-banking several times a day, which may indicate a high level of confidence in such solutions,
- respondents are aware of issues related to computer system security and understand its various aspects; however, they primarily interpret it as protection against data disclosure,
- the majority of respondents have not encountered, or do not know if they have encountered, passive threats, which may indicate the respondents' high confidence in using computer networks,
- similar to the recognition of attack types, when it comes to the perceived significance of cyber threats, viruses were identified as the most recognizable, followed by Trojan horses and Remote Access Trojans (RATs),
- the vast majority of respondents have not personally encountered cybercrime while using e-banking, confirming the high level of confidence in this type of solution,
- in terms of confidence in the security of the respondent bank's computer systems, the majority of respondents regarded them as good and very good, indicating high confidence in the solutions provided by this type of financial institution,
- in evaluating banks' educational efforts in the area of cybersecurity, respondents described them as good or average, which may indicate that they expect their financial institutions to take more proactive measures in this domain,
- respondents indicated medium involvement of institutions such as the Polish Bank Association (Związek Banków Polskich) and the Financial Supervision Commission (Komisja Nadzoru Finansowego) in building awareness of cybersecurity. This indicates an expectation of stronger involvement of the mentioned institutions in educational activities in the area of digital security.

The results of the survey indicate that respondents have a high awareness of cyber threats that can occur when using e-banking services. The research also showed that awareness of cybersecurity issues is known to respondents, but is perceived as insufficient. In addition,

respondents indicate the need for banks to increase educational activities related to their security in using online and mobile e-banking communication channels.

The research conducted also had some limitations. The first was that the research sample was limited to the academic community. The second limitation was related to conducting the research only in one country. The third referred to conducting the analyses only from the point of view of bank customers who are users of electronic banking. The study did not include banks themselves as the second key entity, highly exposed to threats originating from computer networks.

The analysis conducted fits into the research gap in the area of perception of computer security by individual users of electronic services provided by banks to the mass customer. The presented research can also be useful for practitioners operating in the financial sector to create ventures aimed at raising awareness of cybersecurity among their customers.

Further research in this area should be expanded in three main directions. The first is to expand the research group to include other electronic banking users. The second would be to study the factors influencing the development of cybersecurity awareness with a particular focus on the solutions used by banks. The third direction should be an attempt to use international comparisons to examine whether, for example, cultural factors and the level of IT adoption in a given country affect cybersecurity awareness.

References

1. *A Regulatory Framework for Improving E-banking Security* (2024, June 24). SciSpace - Paper. https://doi.org/10.1109/icccnt61001.2024.10724553
2. *A Study on Customer Awareness Towards Cyber Security in Banking Industry with Special Reference to Sulthan Bathery Municipality* (2025). ResearchGate. https://doi.org/10.55041/IJSREM40978
3. *A survey of cybersecurity threats and countermeasures in the Indian financial sector | Request PDF* (n.d.). ResearchGate. https://doi.org/10.47974/JIOS-1568
4. Ahmad, I., Khan, S., Iqbal, S. (2024). Guardians of the vault: Unmasking online threats and fortifying e-banking security, a systematic review. *Journal of Financial Crime*, *31*(6), 1485-1501. https://doi.org/10.1108/JFC-11-2023-0302
5. Alghazo, J.M., Kazmi, Z., Latif, G. (2017). C*yber security analysis of internet banking in emerging countries: User and bank perspectives.* 2017 4th IEEE International Conference on Engineering Technologies and Applied Sciences (ICETAS), 1-6. https://doi.org/10.1109/ICETAS.2017.8277910
6. Arora, D., Garg, M., Mongia, S. (2022). *Global Case Studies, Domains and Used Methodologies Concerning Cyber Security in Online banking: A Review.* 2022 10th

International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO), 1-7. https://doi.org/10.1109/ICRITO56286.2022.9965094

7. Bandera, R., Grzywacz, J. (2016). Zagrożenia bezpieczeństwa w bankowości elektronicznej. *Zeszyty Naukowe PWSZ w Płocku. Nauki Ekonomiczne*, *2(24)*, 151-168.
8. Batorski, D. (2015). Technologies and Media in Households and Lives of Poles. *Contemporary Economics*, *9*(4), 367-389.
9. *Behavioural Insights Into Cybersecurity Practices Among Digital Banking Consumers in South Africa* (2024). ResearchGate. https://doi.org/10.55927/ijba.v3i4.5515
10. Cele, N.N., Kwenda, S. (2024). Do cybersecurity threats and risks have an impact on the adoption of digital banking? A systematic literature review. *Journal of Financial Crime*, *32*(1), 31-48. https://doi.org/10.1108/JFC-10-2023-0263
11. Chmielarz, W., Zborowski, M. (2024). On Comparison of the Results of Selected Multicriteria Methods Applied in the Assessment Banking Websites in Poland in 2022. In: M. Hernes, J. Wątróbski (Eds.), *Emerging Challenges in Intelligent Management Information Systems* (pp. 268-288). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-66761-9_22
12. Chmielarz, W., Zborowski, M., Fandrejewska, A., Atasever, M. (2021). Poland–Turkey Comparison of Mobile Payments Quality in Pandemic Time. *Journal of Risk and Financial Management*, *14*(9), Article 9. https://doi.org/10.3390/jrfm14090426
13. Cybersecurity Risk Assessment In Banking: Methodologies And Best Practices (2023). *Computer Science & IT Research Journal*, *4*(3), Article 3. https://doi.org/10.51594/csitrj.v4i3.659
14. Deshmukh, K. (2024). Risk Analysis in Online Banking Systems. *IJFMR - International Journal For Multidisciplinary Research*, *6*(3). https://doi.org/10.36948/ijfmr.2024.v06i03.21892
15. Dongol, R., Chatterjee, J. (2019). *Robust Security Framework for Mitigating Cyber Threats in Banking Payment System: A Study of Nepal*. https://www.semanticscholar.org/paper/Robust-Security-Framework-for-Mitigating-Cyber-in-A-Dongol-Chatterjee/96db0a7d729dfedbbc913aad97370844df70522c
16. Dziennik Internautów (n.d.). *Ataki hakerskie na banki—Rosnące zagrożenie dla polskiego sektora finansowego.* Retrieved from: https://di.com.pl/ataki-hakerskie-na-banki-rosnace-zagrozenie-dla-polskiego-sektora-finansowego-70912, May 9, 2025.
17. *E-banking: Online Transactions and Security Measures* (n.d.). ResearchGate. https://doi.org/10.19026/rjaset.7.766
18. *FTBS 2023: Cyberbezpieczeństwo banków – zagrożenia i nowe perspektywy* (2023, June 5). https://bank.pl/ftbs-2023-cyberbezpieczenstwo-bankow-zagrozenia-i-nowe-perspektywy/

19. Garba, J., Kaur, J., Ibrahim, E.N.M. (2023). Design of a conceptual framework for cybersecurity culture amongst online banking users in Nigeria. *Nigerian Journal of Technology*, *42*(3), Article 3. https://doi.org/10.4314/njt.v42i3.13
20. Garfinkel, S., Spafford, G., Schwartz, A. (2003). *Practical UNIX and Internet Security*. O'Reilly Media, Inc.
21. Gupta, M., Lee, J., Rao, H.R., Gupta, M., Lee, J., Rao, H.R. (1 C.E.). *Implications of FFIEC Guidance on Authentication in Electronic Banking* (implications-ffiec-guidance-authentication-electronic). IGI Global Scientific Publishing. https://doi.org/10.4018/978-1-59904-855-0.ch022
22. Hajduk-Stelmachowicz, M., Iwan, K. (2018). Zarządzanie bezpieczeństwem informacji w obszarze bankowości elektronicznej wobec zjawiska cyberprzestępczości—Aspekt indywidualny. *Roczniki Kolegium Analiz Ekonomicznych, no. 49, Społeczno-ekonomiczne aspekty rozwoju gospodarki cyfrowej : koncepcje zarządzania i bezpieczeństwa*. Szkoła Główna Handlowa, 489-499.
23. Hajjisaaid, A., Ahmed, Y.A. (2020). Secure Electronic Banking Authentication—Survey. *2020 International Conference on Computing and Information Technology (ICCIT-1441)*, 1-4. https://doi.org/10.1109/ICCIT-144147971.2020.9213767
24. Informatycznej, R.B.K. (2021, April 23). *Zabezpieczenia systemów informatycznych—Profesjonalny Outsourcing IT Warszawa dla firm—Kompania Informatyczna*. https://kompaniainformatyczna.pl/2021/04/23/zabezpieczenia-systemow-informatycznych/
25. Kangapi, Thembakazi, M., Chindenga, E. (2022). Towards a Cybersecurity Culture Framework for Mobile Banking in South Africa. *2022 IST-Africa Conference (IST-Africa)*, 1-8. https://doi.org/10.23919/IST-Africa56635.2022.9845633
26. Karim, N.A., Khashan, O.A., Kanaker, H., Abdulraheem, W.K., Alshinwan, M., Al-Banna, A.-K. (2024). Online Banking User Authentication Methods: A Systematic Literature Review. *IEEE Access*, *12*, 741-757. https://doi.org/10.1109/ACCESS.2023.3346045
27. Korzeń, K. (2007). *Bankowość elektroniczna jako kanał dystrybucji usług bankowych*. Intelgraf - Anna Dygas.
28. Krzysztoszek, M. (2017). *Bankowość elektroniczna w teorii i praktyce Materiały edukacyjne dla środowiska szkolnego*. Komisji Nadzoru Finansowego. https://www.knf.gov.pl/knf/pl/komponenty/img/Bankow%C5%9B%C4%87%20elektroniczna%20w%20teorii%20i%20praktyce_60154.%20Materia%C5%82y%20dla%20%C5%9Brodowiska%20szkolnego_60154.pdf
29. Kurek, M., Burzyk, P., Kieszkowski, M. (2024). *Barometr cyberbezpieczeństwa 2024, Na fali, czy w labiryncie regulacji?* KPMG Poland. https://assets.kpmg.com/content/dam/kpmg/pl/pdf/2024/02/pl-Raport-KPMG-w-Polsce-Barometr-cyberbezpiecze%C5%84stwa-2024.pdf

30. Malinka, K., Hujňák, O., Hanáček, P., Hellebrandt, L. (2022). E-Banking Security Study—10 Years Later. *IEEE Access*, *10*, 16681-16699. https://doi.org/10.1109/ACCESS.2022.3149475
31. Mazurek, W. (2023). Bankowość elektroniczna w Polsce w opinii klientów indywidualnych w świetle wyników badania własnego. *Internetowy Kwartalnik Antymonopolowy i Regulacyjny*, *12*(7), 9-31. https://doi.org/10.7172/2299-5749.IKAR.7.12.1
32. Mohammed, J.A., Mohammed, J.S. (2024). Authenticated E- Bank System Based on RBAC Model. *International Research Journal of Innovations in Engineering and Technology*, *8*(5), 150-155. https://doi.org/10.47001/IRJIET/2024.805023
33. Olczak, M., Brakoniecki, M., Sterczała, P., Borek, J. (2015). *Bezpieczeństwo bankowości elektronicznej, II Raport Specjalny*. Obserwatorium.biz. https://obserwatorium.biz/wp-content/uploads/2018/11/2_PL.pdf
34. Oyewole, A.T., Okoye, C.C., Ofodile, O.C., Ugochukwu, C.E. (2024). Cybersecurity risks in online banking: A detailed review and preventive strategies applicatio. *World Journal of Advanced Research and Reviews*, *21*(3), 625-643. https://doi.org/10.30574/wjarr.2024.21.3.0707
35. Poireault, K. (2023, November 30). Manufacturing Top Targeted Industry in Record-Breaking Cyber Extortion. *Infosecurity Magazine.* https://www.infosecurity-magazine.com/news/manufacturing-top-targeted-orange/
36. *Prevention Of Cyber Frauds In The Banking Sector* (n.d.). ResearchGate. https://doi.org/10.55041/ISJEM01341
37. *Raport Roczny CSIRT KNF 2023* (2023). Urząd Komisji Nadzoru Finansowego. https://www.knf.gov.pl/knf/pl/komponenty/img/Raport_roczny_CSIRT_KNF_88762.pdf
38. Sanusi, I.B. (2015, June 1). *Assessment on User Awareness of Security Aspects in E-Banking*. https://www.semanticscholar.org/paper/Assessment-on-User-Awareness-of-Security-Aspects-in-Sanusi/019bd8ea329d9b9871be030c7594f1b1f5671b08
39. Schwabe, M. (2023). Zaufanie jako niezbędny element funkcjonowania organizacji. *Studia i Prace Kolegium Zarządzania i Finansów*, *189*, Article 189. https://doi.org/10.33119/SIP.2023.189.7
40. Siemieniuk, N., Zalewska-Bochenko, A. (2017). Bezpieczeństwo systemów informatycznych w instytucjach bankowych. *Roczniki Kolegium Analiz Ekonomicznych, no. 44, Uwarunkowania funkcjonowania gospodarki cyfrowej*. Szkoła Główna Handlowa, 55-67.
41. Stallings, W., Brown, L. (2019). *Bezpieczeństwo systemów informatycznych. Zasady i praktyka (VI).* Helion. https://helion.pl/ksiazki/bezpieczenstwo-systemow-informatycznych-zasady-i-praktyka-wydanie-iv-tom-1-william-stallings-lawrie-brown,bsi41v.htm
42. Taherdoost, H. (2022). Cybersecurity vs. Information Security. *Procedia Computer Science*, *215*, 483-487. https://doi.org/10.1016/j.procs.2022.12.050

43. *Top Cybersecurity Statistics for 2024 | Cobalt* (n.d.). Retrieved from: https://www.cobalt.io/blog/cybersecurity-statistics-2024, May 9, 2025.
44. Wyrębek, H. (2012). Bezpieczeństwo w zarządzaniu informacją na poziomie systemów informatycznych. *Zeszyty Naukowe Uniwersytetu Przyrodniczo-Humanistycznego w Siedlcach. Seria: Administracja i Zarządzanie*, *22*. https://bazawiedzy.uws.edu.pl/info/article/UPH6f5ecdbd560f40568fb33822137d0f36/
45. Zalewska-Bochenko, A., Siemieniuk, Ł. (2010). Bankowość, bankowość elektroniczna a etyka. *Ekonomia-Polityka-Etyka. Tom III.* A.F. Bocian (ed.), 235-244.
46. Zborowski, M., Chmielarz, W. (2023). *Sensitivity analysis of the criteria weights used in selected MCDA methods in the multi-criteria assessment of banking services in Poland in 2022*. 1217-1222. https://doi.org/10.15439/2023F3745
47. Zborowski, M., Chmielarz, W. (2024). On The Application Of The Conversion Method For Website Evaluation Of Polish Banks In 2022. *Humanities and Social Sciences*, *31*(3), Article 3. https://doi.org/10.7862/rz.2024.hss.38

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