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FOREWORD

We are delighted to present the latest number of *Silesian University of Technology. Scientific Papers. Organization and Management Series*. This edition explores diverse topics, reflecting the complexity and dynamics of contemporary management challenges across multiple domains. The collection includes research on strategic decision-making, innovation in project management, energy sector transitions, and Smart City concepts, all of which highlight practical and theoretical advancements. With contributions examining sustainability, technology, and organizational development, this issue serves as a bridge between traditional management methods and emerging, innovative practices. Through articles ranging from the role of artificial intelligence in finance and project management to analyses of environmental impacts and enterprise growth strategies, this volume offers valuable insights for researchers, practitioners, and policymakers seeking to navigate evolving global challenges. The variety of studies underscores the necessity of interdisciplinary approaches and innovative solutions in addressing today's most pressing issues.

Aleksandra Czupryna-Nowak
Marcin Wyskwarski

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EFFICIENCY OF INFORMATION TRANSFER IN COMPUTER SYSTEMS. COMPARATIVE ANALYSIS FOR DIFFERENT NATURAL LANGUAGES

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Purpose: The paper provides a comparative analysis of coding algorithms for three different natural languages. The research aimes at understanding, comparing and evaluating the effectiveness of coding algorithms based on the example of a complex text using the Polish, English and German languages. The main goals of the work include the comprehensive comparative analysis of each tested algorithm. The assessment of algorithms effectiveness in terms of compression level, codeword length, coding optimality and information entropy has been presented. Measurement of the time required by each algorithm to compress the text based on a given language has been defined. The timing analysis aimed at understanding which algorithm exhibits the best performance in terms of processing speed has also been carried out. Developed detailed conclusions based on collected experimental data, results and comparative analysis have been included. Presentation of the advantages, disadvantages and potential applications of each analyzed coding algorithm in the context of literary texts in various national languages has been provided. The project's goal includes analyzing the compression efficiency and understanding the behavior of these algorithms in diverse natural languages.
Design/methodology/approach: Data visualization methods to present differences in information algorithms for different national languages have been applied in the paper.
Findings: Analysing the compression efficiency and understanding the mentioned algorithms' behavior in diverse natural languages.
Research limitations/implications: Surveys discussed in this paper may contribute to further empirical studies, including but not limiting the initial works, trying to improve the analysis.
Practical implications: The study provides essential information on the fact that natural language complexity can be applyed to the analysis. The results highlight the importance of maintaining and adapting information measures to obtain differences for natural languages.

Originality/value: This study stands out from other works based on comparing three natural languages and different algorithms.
Keywords: information, computer systems, national languages, algorithms.
Category of the paper: General review, Research paper.

1. Introduction

Data compression is a technique that transforms data from one representation to a new one containing the same information with the smallest possible size (Pu, 2006). Data size is reduced by removing excess information. The technique reduces the costs of data storing and/or transmitting, reducing the amount of transmitted information, which results in increasing the throughput of the communication channel, which in turn enables the transmission of bigger amount of data.

1.1. Related Works

The subject literature on the effectiveness of coding algorithms in various natural languages is rich and diverse. These studies often emphasize the influence of linguistic structure and cultural context on the selection and effectiveness of algorithms. In future, it is worth continuing the research in order to understand how encoding algorithms can be adapted to the specific needs of different natural languages.

Amit J., Kamaljit I. L (Amit et al., 2014) compared statistical compression techniques to check the effectiveness of the compression algorithm on English text data. Sharma, Neha & Batra, Usha. (Sharma, Neha et al., 2018), analyzed data compression methods applied in information security techniques such as steganography, cryptography, etc. They compared lossy and lossless techniques concluding that lossy techniques perform better quantitatively while lossless techniques are better qualitatively. However, lossless techniques are more effective because no data loss occurs. Stecuła et al. investigated the possibility of applying the Esperanto language for the text compression (Stecula et al., 2022). They compared the results of text compression in the artificial Esperanto language with compression in natural languages like Polish and English. An interesting result of the work was that the Esperanto language allowed for a higher degree of compression than the studied natural languages. It was concluded that Esperanto provided the space-saving way of storing information. Researchers also conducted comparative studies of document compression techniques in languages that differ significantly in spelling and grammar and originated from distant cultural circles (Revuz, 1992; Sculley, 2006; Ghwanmeh et al., 2006; Abu-Errub, Aymen, 2014). In Alasmer et al., a comparison was made between the performance of compression techniques in Arabic and English (Alasmer et al., 2013). They identifyed two or more component data documents in both languages to compress a data document. According to the authors, the data comparison in the Arabic language was provided for the first time.

2. Data Compresion Techniques

2.1. The Huffman algorithm

The Huffman algorithm (Huffman, 1952) is a static entropy coding technique that assigns shorter binary codes to more common symbols in the text. This optimization procedure allocates smaller bits of code to symbols with a higher frequency of occurrence. This leads to effective compression. The algorithm's operation principle is to create a binary tree (Figure 1), where the leaves represent text symbols and the paths from the root to the leaves specify the codes for these symbols. When creating a tree, symbols have been grouped into pairs and then into larger groups based on their frequency of occurrence. The procedure continues until a single tree root is obtained and each symbol is assigned a code binary.

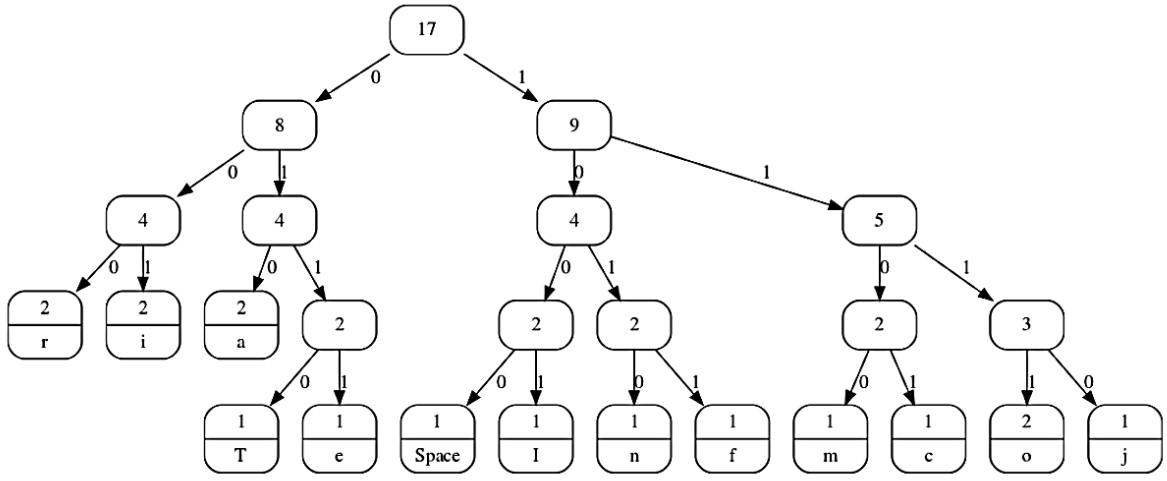

Figure 1. Binary tree created applying Huffman algorithm for code word "Information Theory".
Source: Authors' own study.

Thanks to its simplicity and efficiency, Huffman algorithm has become one of the key algorithms in data compression.

Advantages of the algorithm:

- Coding efficiency – it generates optimal codes for symbols, which significantly reduces data size.
- Simplicity of implementation - this algorithm is relatively simple and does not require a big amount of computing power.
- Algorithm works well for various types of data – it compresses text data, images and other types of information effectively.

Disadvantages of the algorithm:

- Rate-dependent encoding - the algorithm's effectiveness relies on determining the frequency of symbols accurately. When these frequencies change, the coding efficiency may decrease.

– Algorithm requires transmission of a code table – it involves the transmission of additional information (code table), which may increase the size of the transferred data in the case of small files.

The Huffman algorithm is one of the fundamental algorithms in data compression and it is still applied in many fields despite the existence of more advanced techniques. Its simplicity, efficiency and flexibility in compressing various data types make it an essential tool in today's digital world.

2.2. Shannon-Fano algorithm

The Shannon-Fano algorithm (Kaur, Sandeep et al., 2016) is an entropy coding technique that assigns a binary code to symbols in text based on their occurrence probabilities. This is a procedure in which symbols are sorted by frequency of occurrence and then divided into groups in an attempt to maintain uniformity in the length of the binary codes for these groups. The algorithm's operation principle is to divide the set of symbols into smaller groups with similar probabilities of occurrence. Each group is then encoded using binary codes, trying to achieve as uniform code lengths as possible for the symbols in a given group.

Advantages of the algorithm:

– Data Size Reduction – it offers data size reduction by assigning shorter codes to more common symbols.
– Simplicity and intuitiveness - this algorithm is easy to understand and implement, which makes it easy to use in various applications.
– Performance for non-uniform distributions – it handles non-uniform symbol distributions effectively, offering relatively good results for various data types.

Disadvantages of the algorithm:

– Lack of optimality for some data - the algorithm does not always generate optimal codes, especially for data where some symbols have significantly different frequencies.
– The algorithm requires sending additional information. Like the Huffman algorithm, the encoded data must be preceded by information about the assignment of codes to symbols, which may increase the size of the transmitted data.

The Shannon-Fano algorithm was one of the pioneering approaches to the problem of encoding based on the probability of symbols. Although, it is no longer the dominant technique in data compression, its simplicity and understandability still provide the foundation for more advanced methods.

3. Methodology

A comparative analysis of three data compression algorithms was carried out to examine their effectiveness for different languages - Polish, English, German, based on selected fragments from the book "The Lord of the Rings". The experiment also considered different text sizes: 5,000, 15,000, and 25,000 lines of text as well as the full-text length.

Each of the analyzed algorithms was tested on the same fragment of the text "The Lord of the Rings" in each of the three languages. The performance of the algorithms was assessed using the same text fragments to ensure the comparability of results and objectivity of the analysis. Original translations were used.

3.1. Analyzed Parameters

For each test, the following parameters were measured (Gareth et al., 2002):

- *Text entropy* – Entropy represents the average amount of information in each message from an information source. In other words, it is the average amount of information assigned to a single message, where these values are weighted based on the probabilities of occurrence of individual messages. Entropy was calculated for each text size in every language.
- *Algorithm execution time* – The time needed to create each code was measured for every algorithm and language. The goal was to understand which algorithm had better time performance. The time was counted for the execution of each algorithm for each size and each language. The time from the start of the algorithm to the generation of the entire code was measured.
- *Average codeword length* – The average length of the codeword generated by each algorithm for the analyzed texts was calculated. Comparing the size of these words allowed for the assessment of coding efficiency. The calculations were made applying the following formula:

$$L = \sum_{i=1}^{q} p_i \, l_i \tag{1}$$

where:
q is the length of the code,
p_i is the probability of the ith symbol appearing in the text,
l_i represents the length of the code assigned to the ith symbol.

– *Code efficiency* – An assessment of coding efficiency was carried out, i.e., the average value of the message was calculated based on the average size of the codeword. Thanks to this parameter, it was possible to determine how efficient the created code was. The following formula was used:

$$\eta = \frac{H(S)}{L} \tag{2}$$

where H(S) is the entropy of the message source.

3.2. Analysis procedure

For each sample, i.e., for each language and text size, an analysis was performed applying two coding algorithms. The texts were prepared correctly and encoded and the following parameters were calculated: entropy, code execution time, average codeword length, and code efficiency. All results obtained from the analysis were carefully documented. Numerical data, calculation results and any other relevant information were saved for later analysis and comparison with the results of individual algorithms under different conditions. The study was carried out carefully and systematically considering various aspects of the work of individual algorithms depending on the language and text size.

3.3. Analysis results

Table 1 shows the collected measurements. Where Q denotes the algorithm used, Len(s) (lines of text) represents the length of the sample text, t(Q, s) the time needed to solve the problem, Avg(Q, s) the average length of the codeword, E(Q, s) the coding efficiency, and LNG denotes text language.

Table 1.
Representation of measurement results of selected algorithms

Q	Len(s)	H(Q,s)	t(Q,s)	Avg(Q,s)	E(Q,s)	LNG
Huffman	5000	4,46702	0,00017905	4,50793	99,0925%	EN
Shannon-Fano	5000	4,46702	0,00017548	4,58390	97,4501%	EN
Huffman	15000	4,45777	0,00030494	4,50000	99,0616%	EN
Shannon-Fano	15000	4,45777	0,00025225	4,57049	97,5339%	EN
Huffman	25000	4,46378	0,00029540	4,50627	99,0571%	EN
Shannon-Fano	25000	4,46378	0,00030851	4,57654	97,5362%	EN
Huffman	-	4,45904	0,00019002	4,50159	99,0549%	EN
Shannon-Fano	-	4,45904	0,00019908	457241	97,5206%	EN
Huffman	5000	4,82957	0,00020552	4,84957	99,5877%	PL
Shannon-Fano	5000	4,82957	0,00021648	4,90895	98,3831%	PL
Huffman	15000	4,83219	0,00023437	4,85177	99,5964%	PL
Shannon-Fano	15000	4,83219	0,00024295	4.91728	98,2695%	PL
Huffman	25000	4,83588	0,00024605	4,85529	99,6002%	PL
Shannon-Fano	25.000	4,83588	0,00025535	4,92219	98,2465%	PL
Huffman	-	4,85509	0,00028253	4,87517	99,5880%	PL
Shannon-Fano	-	4,85509	0,00028682	494156	98,2502%	PL
Huffman	5000	4.57040	0,00023556	4,60350	99,2810%	DE
Shannon-Fano	5000	4.57040	0,00028777	4,71581	96,9164%	DE

Cont. table 1.

Huffman	15000	4,56260	0,00034523	4,59622	99,2687%	DE
Shannon-Fano	15000	4,56260	0,00022149	4,70527	96,9679%	DE
Huffman	25000	4,56495	0,00033951	4,59834	99,2737%	DE
Shannon-Fano	25000	4,56495	0,00024533	4,70762	96,9693%	DE
Huffman	-	4,56067	0,00021076	4,59470	99,2593%	DE
Shannon-Fano	-	4,56067	0,00021553	4,69456	97,1480%	DE

Source: Authors' own study.

4. Discussion

The charts below (Figure 2-4) show code efficiency as a function of the text length for the languages tested. The x-axis shows the size of the text. It is worth explaining that the value 100 marked in the charts means the entire text, not 100,000 text lines, as the chart suggests. The measurements show that Huffman's algorithm better performance in each language case. Moreover, the results are very similar for different text lengths. In the Shannon-Fano algorithm, the text length is more important but the text length has a different impact for each language. Both algorithms presented the best performance for the Polish language and the worst for the German language.

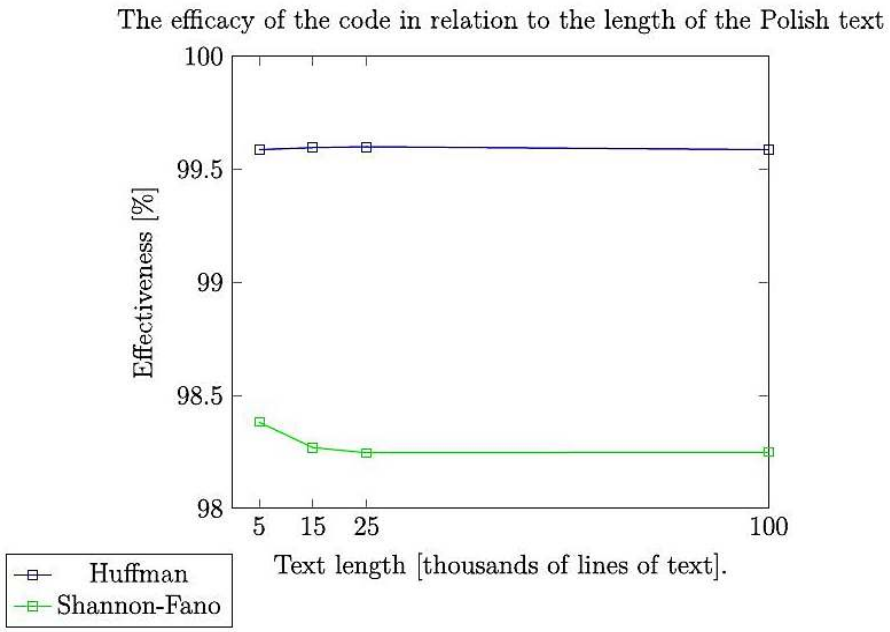

Figure 2. Code efficiency as a function of text length in Polish.

Source: Authors' own study.

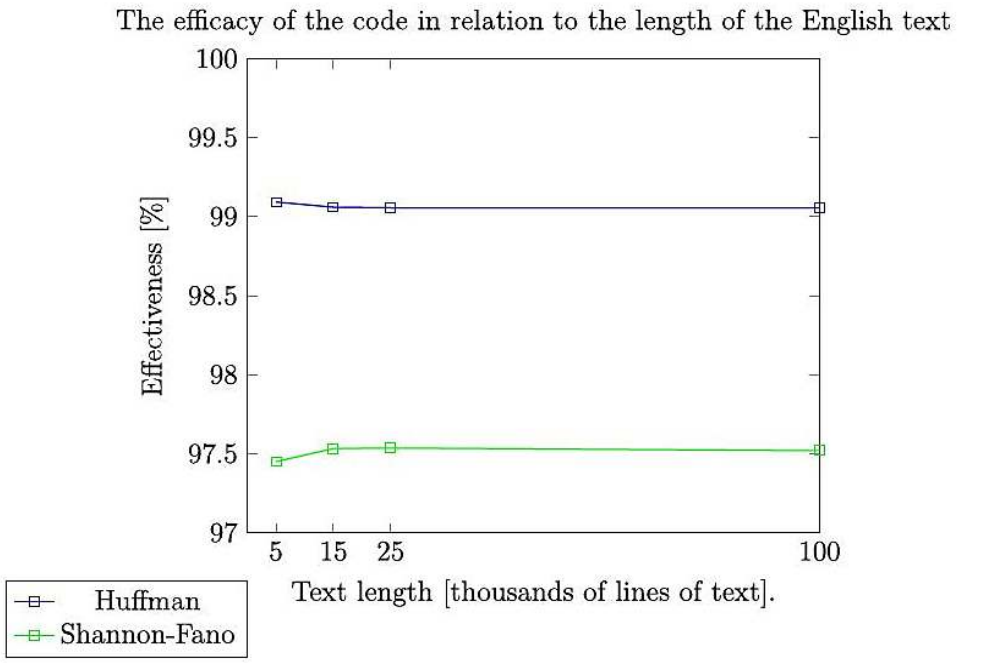

Figure 3. Code efficiency as a function of text length in English.

Source: Authors' own study.

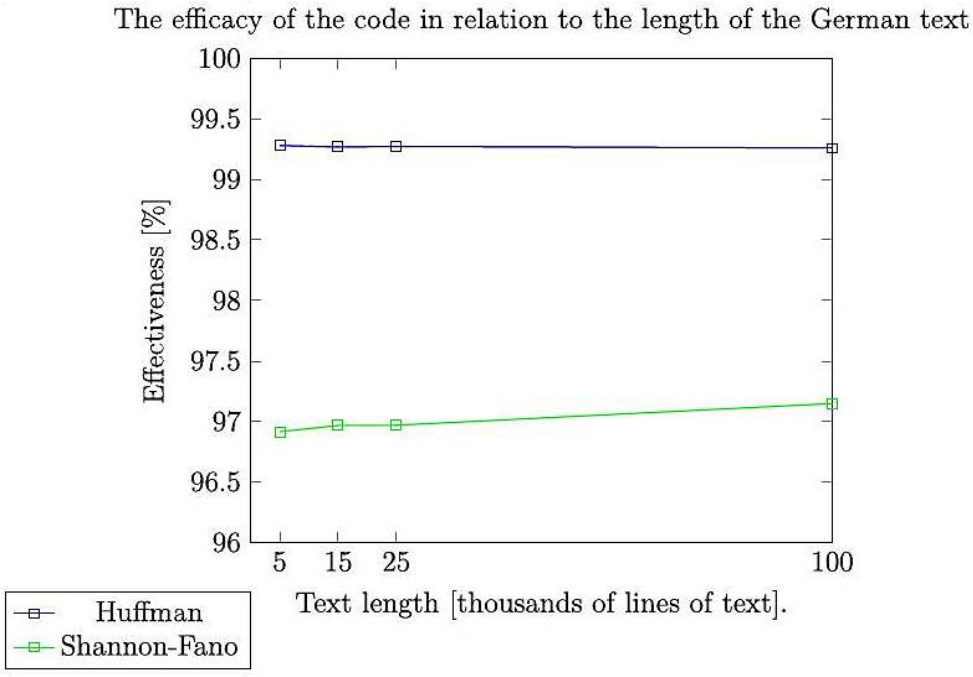

Figure 4. Code efficiency as a function of text length in German.

Source: Authors' own study.

5. Conclusions

The paper explored the efficiency of coding algorithms for data compression across languages - Polish, English and German, through comparative analysis specifically focusing on Huffman and Shannon-Fano algorithms. Key conclusions from the study are as follows:

1. Algorithm Efficiency – The Huffman algorithm consistently outperformed the Shannon-Fano algorithm regarding compression efficiency across all tested languages. It provided higher data reduction, smaller average codeword lengths and better time efficiency.
2. Language Dependence – The study highlighted how language intricacies impact algorithm performance. In the Polish language, the highest compression efficiency was achieved, followed by English and the lowest efficiency was observed in German. This was attributed to the structural and linguistic features inherent to each language.
3. Scalability and Text Length – The Huffman algorithm maintained relatively stable efficiency, regardless of the text length, whereas the Shannon-Fano algorithm's efficiency varied more significantly with changes in the text length. This caused the Huffman algorithm more suitable for varied text sizes and scalable applications.
4. Compression in Multilingual Contexts – The study suggested that while the Huffman algorithm was more adaptable across different languages, both algorithms exhibited potential limitations when dealing with language-specific nature. These findings were particularly relevant for applications requiring multilingual data compression, indicating that tailored approaches might enhance further performance.
5. Application Suitability – Due to algorithms optimal performance in multiple contexts, the Huffman algorithm was recommended for applications requiring high compression ratios without significant loss in data integrity.
6. The Shannon-Fano algorithm can serve better in scenarios where simplicity and computational ease is prioritized over peak efficiency.

The research indicates the importance of selecting compression algorithms based on linguistic context and specific application requirements to achieve optimal performance. Further research can explore compression techniques to accommodate unique language structures better, potentially enhancing multilingual data processing.

References

1. Abu-Errub, A. (2014). Arabic Text Classification Algorithm using TFIDF and Chi Square Measurements. *International Journal of Computer Applications*, *93*, pp. 40-45, doi: 10.5120/16223-5674.
2. Alasmer, Z., Zahran, B., Ayyoub, B., Kanan, M., Hammouri, A., Ababneh, J. (2013). A Comparison between English and Arabic Text Compression. *Contemporary Engineering Sciences, 6,* pp. 111-119, doi: 10.12988/ces.2013.13010.
3. Amit, J., Kamaljit, I.L. (2014). A Comparative Study of Lossless Compression Algorithm on Text Data. *International Journal of Electronics and Information Engineering, Vol. 1, No. 1, Sept. 2014,* pp. 45-52.
4. Ghwanmeh, S., Al-Shalabi, R., Kanan, G. (2006). Efficient Data Compression Scheme using Dynamic Huffman Code Applied on Arabic Language. *Journal of Computer Science, 2,* doi: 10.3844/jcssp.2006.885.888.
5. Huffman, D. (1952). A Method for the Construction of Minimum-Redundancy Codes. *Proceedings of the IRE, 40(9)*, pp. 1098-1101, doi:10.1109/JRPROC.1952.273898.
6. Jones, G.A., Jones, J.M. (2002), *Information and Coding Theory*. *Springer Undergraduate Mathematics Series*. London: Springer, ISSN 1615-2085.
7. Kaur, S., Singh, S. (2016). Entropy Coding and Different Coding Techniques. *Journal of Network Communications and Emerging Technologies*, *Vol. 6, Iss. 5,* S2CID 212439287. Archived from the original (PDF) on 2019-12-03. Retrieved 15.09.2024.
8. Pu, I.M. (2006). *Fundamental Data Compression.* Britain: Elsevier.
9. Revuz, D., Zipstein, M. (1992). DZ A text compression algorithm for natural languages. In: A. Apostolico, M. Crochemore, Z. Galil, U. Manber (Ed.), *Combinatorial Pattern Matching. CPM*. *Lecture Notes in Computer Science*, *Vol. 644*. Berlin/Heidelberg: Springer, doi: https://doi.org/10.1007/3-540-56024-6_16.
10. Sculley, D., Brodley, C. (2006). *Compression and Machine Learning: A New Perspective on Feature Space Vectors*. Snowbird, UT, USA: IEEE, pp. 332-341, doi:10.1109/DCC.2006.13.
11. Sharma, N., Batra, U. (2018). Performance analysis of compression algorithms for information security: A Review. *ICST Transactions on Scalable Information Systems*, *7(27), 163503*, doi:10.4108/eai.13-7-2018.163503.
12. Stecuła, B., Stecuła, K., Kapczyński, A. (2022). Compression of Text in Selected Languages—Efficiency, Volume, and Time Comparison. *Sensors, 22(177), 6393,* doi: 0.3390/s22176393.

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CHALLENGES FACING ENERGY AND TRANSPORT ENTERPRISES IN THE ERA OF ZERO EMISSIONS

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Purpose: The aim of the research is to identify ways and directions of development of enterprises from the energy and transport sectors, aiming to achieve net zero emissions by 2050. Additionally, the research aims to examine the connections, dependencies and mutual impacts between these sectors.
Design/methodology/approach: The research method used was based on the secondary research method (desk research), which included a detailed analysis of issues published in scientific papers, reports of energy and transport companies and international organizations.
Findings: The use of innovative technical and technological solutions, as well as alternative fuels in the energy and transport sectors, contributes significantly to reducing greenhouse gas emissions. The use of e-fuels and electric batteries can reduce emissions in the transport sector by over 80%. The use of renewable energy sources significantly lowers carbon dioxide emissions, and the use of clean hydrogen is projected to account for over 20% of global electricity production by 2050.
Research limitations/implications: While source research provides valuable insights based on available information, it may not capture the nuance and contextual detail (which is a limitation) that can be gained through direct interaction with industry professionals. Conducting interviews or surveys with senior executives (CEOs) would enable a more complete understanding of the decision-making processes, organizational dynamics and barriers that energy and transport companies face in their pursuit of zero emissions. The next stage of research will be carried out based on the primary research referred to above.
Practical implications: The research results can be used by people managing enterprises in the energy and transport sectors and by politicians responsible for creating economic development policies at the national and local levels.
Social implications: Reducing the emission intensity of the energy and transport sectors will help achieve climate goals, improve air quality, and enable more efficient use of energy, which will translate into benefits not only for the economy but also for local communities and individuals.
Originality/value: The novelty of the research is a comprehensive approach to the two sectors that have the greatest impact on the environment, showing connections and common actions that can be taken to achieve a zero-emission economy.
Keywords: energy, transport, enterprises, zero emission, RES, innovations.
Category of the paper: research paper.

1. Introduction

The growing challenges associated with the environment and climate change are driving various initiatives by enterprises in the energy and transportation sectors. These sectors constitute a crucial part of the global economy but are also major emitters of greenhouse gases, contributing to climate change. Therefore, enterprises operating in these sectors are under pressure to reduce their negative impact on the natural environment. Examples presented in the article illustrate various strategies and solutions that enterprises use to achieve goals related to reducing greenhouse gas emissions. In 2023, total emissions from fossil fuels decreased by 8% in the European Union, with over half of this reduction (56%) coming from the energy sector due to the production of energy from renewable sources. Furthermore, measures such as the modernization of existing infrastructure, improvement of energy efficiency, and the introduction of innovative technologies such as energy storage and network management are being implemented to reduce emissions. In the transportation sector, solutions may include promoting electric vehicles, developing infrastructure for electric vehicle charging, supporting public transportation, and promoting alternative fuel sources such as hydrogen or biofuels. Overall, emissions from transportation decreased by 1.5 gigatons of CO_2 in 2020. In the case of the transport sector, CO_2 emissions decreased by 19.4% in 2020 compared to the level in 2019, with emissions decreasing by 56.4% in international aviation, 31.9% in domestic aviation, 24.8% in international shipping, and 14.6% in land transportation: road and rail (Slocat, 2021). In striving to achieve climate neutrality by 2050, further investments in renewable energy sources, including their infrastructure and the development of new technologies, will play a crucial role. These examples not only demonstrate that there are real opportunities to reduce greenhouse gas emissions but also prove that enterprises can play a significant role in combating climate change by investing in sustainable innovative solutions. The energy sector and the transportation sector are inherently linked to the modern functioning of society and the economy. Both sectors play key roles in ensuring the functioning of other sectors of the economy and in carrying out the daily activities of individuals. However, along with these benefits, both sectors also generate significant negative effects on the natural environment, particularly through the emission of greenhouse gases. The task facing managers is to implement solutions related to enterprise management as well as the implementation of innovative technical and technological solutions that will impact emission reduction and enable efficient operation of enterprises and sectors. The energy sector is the main source of greenhouse gas emissions, primarily carbon dioxide (CO_2), which is a byproduct of fossil fuel combustion, such as coal, natural gas, and oil. In 1900, global CO_2 emissions were around 3 trillion tons, in 1960 9 trillion tons, and in 2014 they amounted to 35 trillion tons (Conlen, 2021). Coal-fired power plants, gas-fired power plants, and other industrial installations produce huge amounts of CO_2 during electricity and heat production. Additionally, processes

related to fossil fuel extraction, transportation, and processing also contribute to greenhouse gas emissions. As a result, the energy sector is a major participant in the process of global warming and climate change. To mitigate the effects of climate change, carbon dioxide emissions associated with the energy sector must be reduced. Significant reductions can be achieved by applying appropriate technologies and policies (Papadis, Tsatsaronis, 2020). Similarly, the transportation sector is also a significant source of greenhouse gas emissions, mainly through the combustion of fossil fuels in vehicle engines. Passenger cars, trucks, ships, and airplanes emit large amounts of CO_2, nitrogen oxides (NOx), and other pollutants into the atmosphere. Road transport is particularly problematic due to its large share in greenhouse gas emissions and local effects of smog and air pollution. Universal electrification proves to be a very slow process of implementing gradual changes and is likely to be too slow to significantly contribute to achieving ambitious climate mitigation goals. The greatest potential lies in combining three main innovations: universal electrification, shared mobility, and automation. In addition to technology and innovation to create a new sustainable transportation system, regulations will also be necessary (Brand et al., 2020). In both cases, there is an urgent need to change current practices to reduce the impact of these sectors on climate change and environmental degradation. In the energy sector, accelerating the transition towards clean and renewable energy sources, such as solar energy, wind energy, hydropower, and nuclear energy, is necessary. The introduction of more efficient energy technologies and the promotion of energy savings can also contribute to reducing CO_2 emissions. By 2050, not only should greenhouse gas emissions be eliminated in all sectors of energy, heating, transport, and industry, but also a close connection between these sectors is necessary to ensure maximum synergy and efficiency (Bogdanov et al., 2021). In the transportation sector, it is necessary to increase the share of electric and hybrid vehicles that emit less CO_2 or no CO_2 at all during use. Promoting public transportation, bicycles, and electric vehicles can also reduce dependence on combustion vehicles and limit emissions associated with road transport. Additionally, investments in transportation infrastructure, such as high-speed rail networks, can help reduce greenhouse gas emissions associated with aviation and road transport. Both the energy sector and the transportation sector must take immediate and coordinated action to reduce greenhouse gas emissions and mitigate the effects of climate change. Investments in clean technologies, infrastructure development, and promotion of conscious energy and transportation use are crucial to achieve this goal. Only in this way will it be possible to create a more sustainable and environmentally friendly future. The conducted research not only fills an existing gap in the analysis but also provides a better understanding of the complex context in which both sectors operate. Therefore, the research results can serve as a basis for developing more effective environmental management strategies and decision-making in the future. As a result, the research contributed to expanding knowledge about the impact of human activity on the environment, which can translate into more conscious and effective actions for nature conservation. The initiation and implementation of the research aimed to supplement

a significant gap in existing analysis, focusing on the impact of two sectors commonly recognized as primarily responsible for adverse environmental effects. Through the conducted research, an innovative perspective on this issue was obtained, allowing the identification of key areas of interaction between them and determining the necessary actions required to achieve goals related to reducing greenhouse gas emissions and striving for sustainable development. In this way, these studies contributed to a better understanding of the complex context in which these sectors operate, potentially serving as a basis for more effective environmental management strategies and decision-making in the future. The mutual interaction of these sectors and their intricate connections with emissions require careful examination. The transportation sector, characterized by diverse mobility patterns, and the energy sector, a significant.

2. Structure of the paper

The article is divided into separate chapters, each serving a specific purpose. The structure is described as follows:

Introduction - The first chapter serves as an introduction, providing a comprehensive overview of the background, objectives, and significance of the study.

Materials and Methods - The second chapter discusses the methodology used to conduct the research presented in the article. This section describes specific approaches, tools, and techniques used for data collection and analysis.

Literature Review - The third chapter is dedicated to a comprehensive review of existing literature relevant to the research topic. This involves a critical analysis of scientific works, theories, and empirical studies related to environmentally friendly actions in the transportation and energy sectors, with particular emphasis on environmental protection.

Results and Discussion - The fourth chapter is crucial for presenting the main research findings and initiating an in-depth discussion. It synthesizes empirical conclusions resulting from the analysis of environmentally friendly actions carried out in the transportation and energy sectors, with particular attention to emission and environmental protection aspects. This chapter serves to interpret the results in light of existing literature, outlining connections between theory and empirical observations. Additionally, it encourages discussion on the implications of the findings, their broader significance, and potential directions for future research.

The organized structure of the article enhances the clarity and coherence of the research presentation.

3. Methods

The method of the conducted research primarily relied on the use of secondary research, also known as desk research. This research approach involves analyzing data and information collected by other researchers, institutions, reports, scientific articles, and other publicly available sources. Secondary research allows for a deeper understanding of existing knowledge on a given issue, identification of trends, statistical analysis, and evaluation of the results of previous research. In this study, scientific articles published in journals with Impact Factor (IF) and recognized by the scientific community, as reflected in the high number of citations of the article, were used. Additionally, reports from energy companies, reports from transportation sector companies including land transport, road transport, and railways were also relied upon. The reports used in the study were also reports from international organizations dealing with issues in the energy and transportation sectors. The use of secondary research has many advantages, including saving time and costs, quick access to data, and the ability to analyze long-term trends. Furthermore, it allows for comparing different sources of information and verifying the credibility of data. However, there are also limitations associated with the secondary research method. This may include outdated data, limited availability of some information, and the risk of relying on unreliable or biased sources. Additionally, secondary research may be more general and imprecise than primary research, which may necessitate additional research or interviews to obtain more detailed data. To mitigate the risk of using low-value data, the focus was mainly on scientific papers published in reputable scientific journals, and official websites of institutions and companies were utilized. The choice of these sources was based on the assumption that scientific articles published in recognized journals have undergone a peer review process by experts, ensuring a certain level of credibility and data quality. Moreover, official websites of institutions and companies often provide up-to-date information, reports, and statistical data that are reliable and publicly available. Using reputable scientific journals allows access to the latest research and scientific achievements in a given field. Articles published in these journals are often evaluated for their originality, research methodology, and scientific value by independent reviewers, increasing confidence in their quality and reliability. Additionally, using official websites of institutions and companies allows access to first-hand data, which may be particularly important for information regarding the actions, strategies, and research results conducted by these institutions. As a result, researchers can be confident that they are using current and reliable data, which in turn affects the quality and reliability of the conducted research and analysis. Despite the mentioned limitations associated with desk research, secondary research remains an important tool in the research process, especially in the literature analysis phase before embarking on primary research. Properly conducted secondary research can provide significant information and guidance for further research activities and help in understanding the context and scope of the research problem.

4. Literature Review

Issues relating to the operations of enterprises in the energy and transport sectors constitute a deeply complex research area that engages both scientists and practitioners. This topic is widely discussed and analyzed in scientific literature, sector reports and public debates. Modern society faces significant challenges related to the need to ensure sustainable development, reduce greenhouse gas emissions, protect the natural environment, ensure energy security, increase economic efficiency and meet the growing demand for energy and mobility. These issues require a comprehensive approach and innovative solutions that can contribute to building a more sustainable and effective future. Selected scientific articles covering issues related to emission reduction and actions taken to reduce the harmful impact on the environment in the energy and transport sectors are presented in Table 1.

Table 1.
Selected scientific papers concerning the energy and transport issue

Title of the paper	The main thoughts and ideas contained in the paper
Transport sector	
Impacts of intelligent transportation systems on energy conservation and emission reduction of transport systems: A comprehensive review.	Intelligent traffic management systems can be used to reduce emissions from the transport sector. These innovative solutions have the potential to positively influence traffic flow and reduce the negative impact of transport on the environment (Lv, Shang, 2022).
A review of cleaner alternative fuels for maritime transportation.	Demand for alternative fuels will continue to grow as the transport sector moves towards integrating cleaner fuels to comply with increasing environmental regulations (Al-Enazi et al., 2021).
Review of advanced low-emission technologies for sustainable aviation.	Discussion of the main technological advances used in low-emission aircraft propulsion. Innovative technological solutions such as improved combustion and thermofluids, improved gearbox technology, use of lightweight materials and intelligent engine health management systems. Significant technological advances will be required in the near future to improve fuel efficiency and mitigate the environmental impact of air transport in the future (Ranasinghe, 2019).
Pathways to net-zero emissions from aviation.	Emissions from air transport will continue to be present, so it is important to find ways to reduce them. Taking into account the ever-increasing demand of the industry for liquid fuels with high energy density, competitive substitutes are increasingly sought. Pathways to net-zero aviation can be achieved through ambitious reductions in the demand for air transport and improving the energy efficiency of aircraft (Bergero et al., 2023).
Assessment of railway infrastructure improvements: valuation of costs, energy consumption and emissions.	In rail transport, one of the elements is freight transport. Its efficiency has a significant impact on climate change compared to other modes of transport. Rapid expansion of infrastructure can be seen in many islands as railroads continue to struggle to capture a larger share of the growing total transport volume (Isler et al., 2022).
Factors affecting the emission of pollutants in different types of transportation: A literature review.	Among the various means of transport, it is indicated that rail transport is ecological and causes less environmental pollution compared to other means of transport. As a result of many studies, it is assumed that rail transport is the best means of transport in terms of the environment. In terms of tonne-kilometres transported per unit of energy consumed, rail transport is a more efficient means of transport than road transport (Aminzadegan et al., 2022).

Cont. table 1.

Alternative fuels to reduce greenhouse gas emissions from marine transport and promote UN sustainable development goals	Different prospective pathways and technologies were analyzed and assessed to help the shipping industry to decarbonise its operations. Substantial reductions in carbon emissions require new financial incentives and policies at regional, national and global levels for maritime transport (Rony et al., 2023).
Energy sector	
Digitalisation of Enterprises in the Energy Sector: Drivers—Business Models—Prospective Directions of Changes.	The main factors influencing the digitization of energy companies have been identified within the broader phenomena of Industry 4.0 and Industry 5.0 (Siuta-Tokarska et al., 2022).
Digitization, digital twins, blockchain, and industry 4.0 as elements of management process in enterprises in the energy sector.	Industry 4.0 technologies applied in the energy sector enable increased energy efficiency through enhanced digitization, thus making the energy sector more environmentally friendly (Borowski, 2021).
Getting to zero carbon emissions in the electric power sector.	The energy sector should implement two fundamental actions: reducing greenhouse gas emissions essentially to zero by adopting renewable energy sources and increasing electrification while transitioning away from fossil fuels (Jenkins et al., 2018).
The dynamic impact of carbon reduction and renewable support policies on the electricity sector.	Policies aimed at reducing CO_2 emissions and promoting renewable energy production contribute to enhancing the stability of the energy sector while ensuring energy supply security. Both policies influence operational and investment decisions concerning renewable and conventional generation in the electricity market (Fagiani et al., 2014).
Technologies for carbon dioxide capture: A review applied to energy sectors.	The development of technologies for capturing and utilizing this gas is of great importance for mitigating greenhouse gas emissions (GHG) and limiting their adverse environmental impacts (Vaz Jr et al., 2022).
Policy, regulation effectiveness, and sustainability in the energy sector: A worldwide interval-based composite indicator.	In order to accelerate the transition of the economy to renewable energy, national laws and regulations should be developed and implemented that encourage companies to be responsible for sustainable development. Research shows that energy policy and regulation are critical to deploying renewable energy and managing natural resources (Drago, Gatto, 2022).
Towards the reduction of CO_2 emissions. Paths of pro-ecological transformation of energy mixes in European countries with an above-average share of coal in energy consumption.	Decarbonization of the economy is the most significant challenge for countries where coal has been the primary source of energy production. Therefore, the most effective approach is a rapid and consistent phasing out of coal and its replacement with solar, wind, hydro, or nuclear energy (Jonek-Kowalska, 2022).
Innovation Solution in Photovoltaic Sector	The modern world is moving towards a zero-emission economy; therefore, various actions are being taken to reduce the share of fossil fuels in energy production. Renewable sources also require investment in energy storage. Much attention is paid to the analysis of the economic efficiency of installations and the potential of energy storage in the context of photovoltaic farms is discussed. The development of photovoltaics also requires investment in energy storage. All issues discussed fall within the scope of the development of photovoltaic farms and the optimal use of energy resources (Czepło, Borowski, 2024).
Development of Energy Companies Based on Renewable Energy Sources	There is a very extensive analysis of activities undertaken by enterprises aimed at implementing renewable energy sources (RES) in order to achieve a zero-emission economy. Numerous initiatives are being undertaken to develop the renewable energy sector, thanks to which the impact of companies on global efforts to reduce greenhouse gas emissions is clearly visible (Borowski, Czepło, 2023).

A literature review provides an invaluable tool to facilitate the synthesis and analysis of existing research, theories, and practices in a given field. In the context of reducing emissions in the transport and energy sectors, the literature review allows for an in-depth analysis of actions taken at global, national and local levels. This allows for the identification of trends, the effectiveness of individual strategies, as well as potential areas requiring further research and action.

The completed literature review of emissions reduction efforts in the transportation and energy sectors provides key insights that can serve as a basis for policies, strategies and initiatives in these areas. Electrification of transport, the development of renewable energy sources, improved energy efficiency and the need for cooperation between the public and private sectors prove to be key elements of effective emission reduction. Supporting innovation and engaging society are becoming essential elements in achieving our climate and environmental goals. Thus, the literature review serves not only as an analysis of past achievements, but also as a roadmap towards a sustainable future.

In the field of literature related to the transport sector, great emphasis is placed on reducing emissions through the implementation of various innovative solutions. A review of the literature on emissions reductions in the transport sector highlights key findings on the role of new technologies and innovations. Electrification of transport, the development of low-emission vehicles and the growing importance of public transport are strategies often highlighted by researchers and experts. Examples of successful vehicle-sharing programs and the expansion of electric vehicle infrastructure confirm the effectiveness of these approaches. However, the literature review also highlights the need for coordinated efforts by the public and private sectors to motivate users and develop the necessary infrastructure.

In the literature on energy companies, the main emphasis is on renewable energy sources and increasing energy efficiency. In the energy sector, the literature review extracts key lessons regarding energy transition and energy efficiency improvement. Research points to the growing share of renewable energy, such as solar, wind and hybrid energy, as a key path to reducing emissions. The integration of energy storage technologies and smart energy grids is an additional critical aspect. However, the literature review also highlights the need to convert energy systems and engage society in moving towards a sustainable and low-carbon future.

5. Results and Discussion

5.1. Actions taken by the energy sector

An important element contributing to the development of energy enterprises is a joint initiative based on cooperation and partnership. Energy companies are increasingly working

with governments, non-governmental organizations and other stakeholders to jointly combat climate change. They work with research institutions and universities to support innovation and develop sustainable solutions. Collaboration enables knowledge sharing, joint investments, and coordinated efforts to drive systemic change and accelerate the energy transition (De La Peña et al., 2022).

The transformation of the energy sector can be described as the concept of combining different sectors - sector coupling. Introducing renewable energy into energy-intensive areas such as heating, transport and industry, rather than using fossil fuels, will require many new technologies and regulations. This idea, known as "sector coupling", reflects the need to integrate different sectors of the economy for a sustainable transition to greener and more efficient energy sources. One application of sector coupling is the direct electrification of different processes. For example, renewable electricity can be used in district heating networks, also known as power-to-heat, with technologies such as heat pumps and electric boilers. Electricity can also be used to produce hydrogen or other synthetic gas.

The European Commission reported that in 2021, there were more than 7700 Energy Communities across the European Union. This community involved at least 2 million people and had an installed renewable capacity of 6.3 GW (Maruf, 2023).

Another action taken is to engage in advocacy and political initiatives. Recognizing the importance of supportive policies, utilities actively engage in policy advocacy. They lobby for the implementation of strong climate legislation, renewable energy incentives and carbon pricing mechanisms. By promoting favorable policies, these companies strive to create an enabling environment that encourages the adoption of clean energy technologies and facilitates the transition to a low-carbon economy.

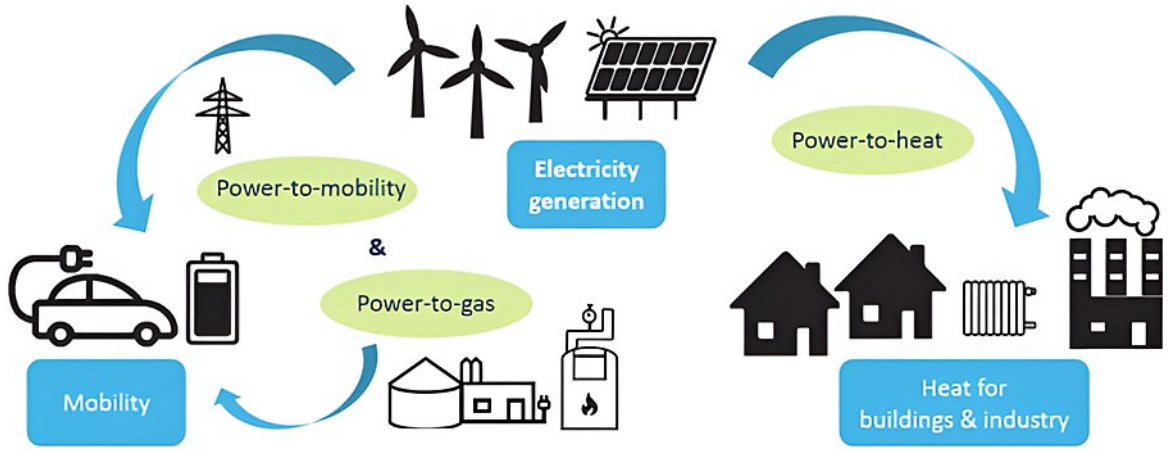

Figure 1. Integrated energy system - the idea of interconnecting (integrating) the energy consuming sectors.

Source: Appunn, 2018.

Another important element mentioned in the literature is transparency of reporting and accountability. To demonstrate their commitment to climate neutrality, energy companies are prioritizing transparent reporting and accountability. They disclose their greenhouse gas emissions, set emissions reduction targets, and report regularly on progress. Transparent reporting increases stakeholder trust, enables benchmarking and facilitates the assessment of companies' sustainability efforts.

5.2. Action taken by transport sector

The transport sector is undertaking a range of initiatives to reduce emissions and achieve zero emissions. A key element is the development of electromobility, including the production of electric vehicles by key automotive manufacturers and the expansion of charging infrastructure. The introduction of alternative fuels, such as biofuels (biodiesel, bioethanol) and hydrogen, also plays a significant role.

Public transport is being modernized and electrified, which includes the introduction of electric buses and trams, as well as investments in high-speed rail, reducing the need for domestic flights. Optimization of logistics and transport management, including fleet management systems and the promotion of intermodality, helps reduce fuel consumption and emissions (Borowski, Karlikowska, 2023).

The use of supportive technologies, such as autonomous vehicles and intelligent transport systems (ITS), contributes to increased driving efficiency and emission reduction. The introduction of stringent emission standards, like Euro standards (Directive 2016/646), obliges manufacturers to create more environmentally friendly engines. Governments also offer subsidies and tax incentives for those investing in eco-friendly vehicles and technologies.

Additionally, educational campaigns increase environmental awareness and promote the use of more sustainable modes of transport, such as bicycles and public transport.

Through these comprehensive actions, the transport sector aims to significantly reduce emissions, with the hope of achieving zero emissions in the future.

5.3. Nexus between energy and transport sectors

A novelty in the activities is the joining of forces of both sectors to reduce greenhouse gas emissions. It is necessary to demonstrate the possibilities of using alternative fuels in transport, as well as to encourage the use of new materials for the production of aircraft and ships and to implement many technical and technological solutions related to traffic management. Combining the forces of the energy and transport sectors to reduce greenhouse gas emissions is presented in Figure 2.

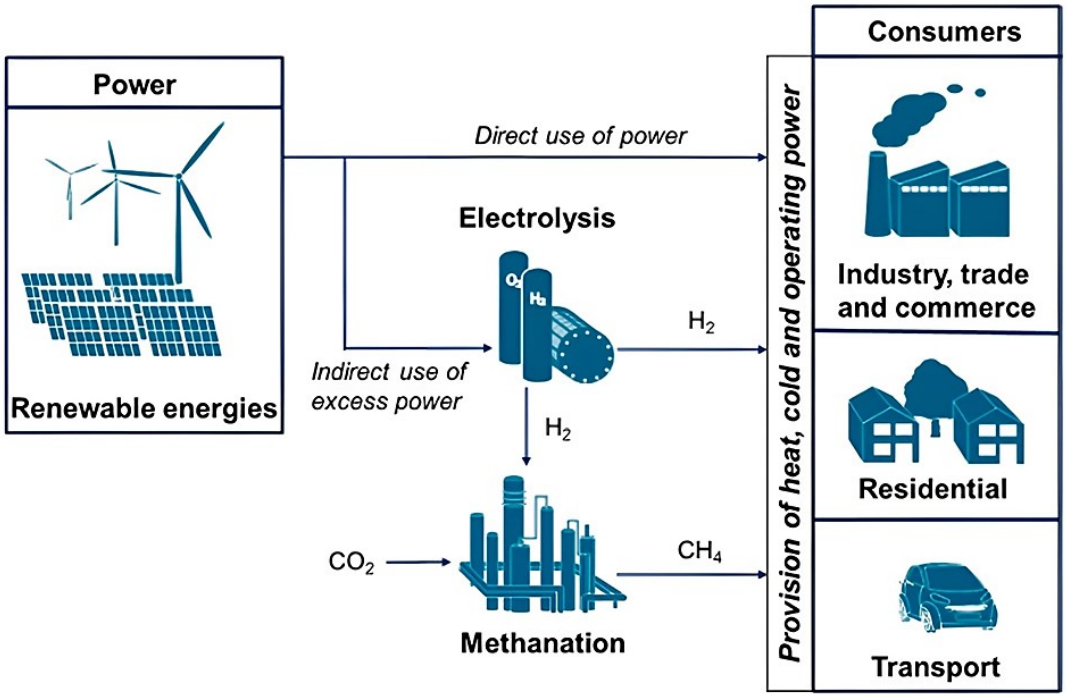

Figure 2. Combining the forces of both sectors to reduce greenhouse gas emissions.
Source: Robinius et al., 2017.

By discovering these synergies, the study provides a roadmap for more integrated and holistic emissions reduction strategies. Stresses the importance of coordinated efforts by the energy and transport sectors to maximize impact and accelerate progress towards climate goals.

Essentially, these studies are extremely important because they serve as a catalyst for cooperation and innovation, highlighting the potential for mutually reinforcing actions between the energy and transport sectors to significantly reduce emissions. They enable better coordination of actions between these sectors, which is crucial for the effective integration of renewable energy sources with transport systems. This creates synergies that lead to more efficient resource use and accelerate the energy transition.

Moreover, these studies stimulate the development of new technologies that can bring revolutionary changes in energy and transport management. Examples include electric vehicles, intelligent transport management systems, and efficient energy storage methods. The results of these studies provide essential data and analyses that support the creation of eco-friendly policies and regulations. Policymakers can rely on solid scientific evidence to implement effective emission reduction strategies.

Industry leaders and stakeholders gain a better understanding of future trends and challenges related to low-emission transport, enabling them to plan investments and develop projects that align with long-term sustainable development goals. The studies identify key areas where emissions can be significantly reduced through technical innovations and changes in the behavior of transport users. The ultimate goal is to achieve a substantial reduction in CO_2 and other greenhouse gas emissions.

6. Conclusion

Joint actions taken by the energy and transport sectors to reduce greenhouse gas emissions have great potential to increase the effectiveness of actions in the fight against climate change. These two sectors are the main sources of CO_2 and other greenhouse gas emissions, so their coordination in efforts to reduce these emissions is crucial to achieving global climate goals.

The shift in both the energy and transport sectors away from traditional fossil fuels such as coal, oil and gas towards renewable energy sources and innovative green fuels is a key element in the fight against climate change. Deploying renewable energy sources such as solar, wind and hydropower in the energy sector can significantly reduce emissions associated with electricity production. However, in the transport sector, the development of electric and hybrid vehicles and the use of alternative fuel sources, such as hydrogen or biofuels, can significantly reduce transport-related emissions.

Coordination of the activities of both sectors allows for synergistic effects, because changes in one sector may affect the other. For example, increasing the share of electric vehicles in transport requires more electricity, which in turn requires more renewable energy production. In this way, actions taken in both sectors can support each other and accelerate the achievement of climate goals.

Achieving the emission target by 2050 requires decisive action and cooperation between the energy and transport sectors. Investments in renewable energy infrastructure, development of green fuel technologies and promotion of effective transport solutions are key to reducing greenhouse gas emissions and ensuring sustainable development. Joint actions of both sectors can bring positive effects not only for the environment, but also for the economy, by creating new jobs, increasing innovation and competitiveness on international markets.

References

1. Al-Enazi, A., Okonkwo, E.C., Bicer, Y., Al-Ansari, T. (2021). A review of cleaner alternative fuels for maritime transportation. *Energy Reports, 7,* pp. 1962-1985.
2. Aminzadegan, S., Shahriari, M., Mehranfar, F., Abramović, B. (2022). Factors affecting the emission of pollutants in different types of transportation: A literature review. *Energy Reports, 8,* pp. 2508-2529.
3. Appunn, K., (2018). *Sector coupling - Shaping an integrated renewable energy system*. Retrieved from: https://www.cleanenergywire.org/factsheets/sector-coupling-shaping-integrated-renewable-power-system, 18.05.2024.

4. Bergero, C., Gosnell, G., Gielen, D., Kang, S., Bazilian, M., Davis, S.J. (2023). Pathways to net-zero emissions from aviation. *Nature Sustainability, 6(4)*, pp. 404-414.
5. Bogdanov, D., Gulagi, A., Fasihi, M., Breyer, C. (2021). Full energy sector transition towards 100% renewable energy supply: Integrating power, heat, transport and industry sectors including desalination. *Applied Energy*, *283, 116273*.
6. Borowski, P.F. (2021). Digitization, digital twins, blockchain, and industry 4.0 as elements of management process in enterprises in the energy sector. *Energies*, *14(7), 1885*.
7. Borowski, P.F., Czepło, F. (2023). Development of Energy Companies Based on Renewable Energy Sources. *Scientific Papers of Silesian University of Technology. Organization & Management*, *No. 189*.
8. Borowski, P.F., Karlikowska, B. (2023). Clean Hydrogen Is a Challenge for Enterprises in the Era of Low-Emission and Zero-Emission Economy. *Energies, 16(3), 1171*. https://doi.org/10.3390/en16031171.
9. Brand, C., Anable, J., Ketsopoulou, I., Watson, J. (2020). Road to zero or road to nowhere? Disrupting transport and energy in a zero carbon world. *Energy Policy*, *139, 111334*.
10. Conlen, M. (2021). *How much carbon dioxide are we emitting?* Retrieved from: https://science.nasa.gov/science-research/earth-science/climate-science/how-much-carbon-dioxide-are-we-emitting/, 18.05.2024.
11. Czepło, F., Borowski, P.F. (2024). Innovation Solution in Photovoltaic Sector. *Energies*, *17(1), 265*.
12. De La Peña, L., Guo, R., Ni, X., Zhang, W. (2022). Accelerating the energy transition to achieve carbon neutrality. Resources. *Conservation and Recycling*, *177, 105957*.
13. Directive 2016/646, Commission Regulation (EU) 2016/646 of 20 April 2016 amending Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6). Retrieved from: https://eur-lex.europa.eu/eli/reg/2016/646/oj, 18.05.2024.
14. Drago, C., Gatto, A. (2022). Policy, regulation effectiveness, and sustainability in the energy sector: A worldwide interval-based composite indicator. *Energy Policy*, *167, 112889*.
15. Fagiani, R., Richstein, J.C., Hakvoort, R., De Vries, L. (2014). The dynamic impact of carbon reduction and renewable support policies on the electricity sector. *Utilities Policy*, *28*, pp. 28-41.
16. Isler, C.A., Blumenfeld, M., Roberts, C. (2022). Assessment of railway infrastructure improvements: valuation of costs, energy consumption and emissions. *Sustainable Energy Technologies and Assessments*, *52, 102179*.
17. Jenkins, J.D., Luke, M., Thernstrom, S. (2018). Getting to zero carbon emissions in the electric power sector. *Joule*, *2(12)*, pp. 2498-2510.

18. Jonek-Kowalska, I. (2022). Towards the reduction of CO2 emissions. Paths of pro-ecological transformation of energy mixes in European countries with an above-average share of coal in energy consumption. *Resources Policy, Vol. 77, 102701*.
19. Lv, Z., Shang, W. (2022). Impacts of intelligent transportation systems on energy conservation and emission reduction of transport systems: A comprehensive review. *Green Technologies and Sustainability*, *100002*.
20. Maruf, M.N.I. (2023). *European energy communities*. Retrieved from: https://build-up.ec.europa.eu/en/resources-and-tools/articles/european-energy-communities-sector-coupling-flexibility-and, 18.05.2024.
21. Papadis, E., Tsatsaronis, G. (2020). Challenges in the decarbonization of the energy sector. *Energy, 205, 118025*.
22. Ranasinghe, K., Guan, K., Gardi, A., Sabatini, R. (2019). Review of advanced low-emission technologies for sustainable aviation. *Energy*, *188, 115945*.
23. Robinius, M., Otto, A., Heuser, P., Welder, L., Syranidis, K., Ryberg, D.S., Grube. T., Markewitz, P., Peters, R., Stolten, D. (2017). Linking the Power and Transport Sectors —Part 1: The Principle of Sector Coupling. *Energies, 10(7), 956*. Retrieved from: https://doi.org/10.3390 /en10070956.
24. Rony, Z.I., Mofijur, M., Hasan, M.M., Rasul, M.G., Jahirul, M.I., Ahmed, S.F., Show, P.L. (2023). Alternative fuels to reduce greenhouse gas emissions from marine transport and promote UN sustainable development goals. *Fuel*, *338*, *127220*.
25. Siuta-Tokarska, B., Kruk, S., Krzemiński, P., Thier, A., Żmija, K. (2022). Digitalisation of Enterprises in the Energy Sector: Drivers—Business Models—Prospective Directions of Changes. *Energies*, *15(23), 8962*.
26. Slocat, (2021). Tracking Trends in a Time of Change: The Need for Radical Action Towards Sustainable Transport Decarbonisation. *Transport and Climate Change Global Status Report* – 2nd edition. Retrieved from: www.tcc-gsr.com.
27. Vaz Jr, S., de Souza, A.P.R., Baeta, B.E.L. (2022). Technologies for carbon dioxide capture: A review applied to energy sectors. *Cleaner Engineering and Technology*, *8*, *100456*.

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SMART CITY ELEMENTS IN URBAN RESILIENCE

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Purpose: To investigate how integrating Smart City technologies enhances urban resilience, enabling cities to adapt, be resilient, and recover in the face of economic, environmental, and social challenges. The study aims to develop a framework that combines technological innovation with urban planning strategies to address key issues such as disaster preparedness, climate change adaptation, and economic stability. Ultimately, the study aims to guide policymakers, urban planners, and stakeholders on leveraging Smart City infrastructure to build resilient, sustainable, and resilient urban environments.
Design/methodology/approach: The paper conducts a literature review and case studies to investigate the impact of innovative city technologies on urban resilience. A literature review on urban resilience and smart city solutions is used to identify key concepts and challenges. Detailed case studies of cities implementing smart technologies to increase their resilience are conducted, including case studies from cities such as Katowice and Rotterdam.
Findings: The study showed that integrating innovative city technologies with urban resilience elements significantly increases the ability of cities to adapt, resist, and recover in the face of economic, environmental, and social challenges. Key factors supporting resilience were identified, such as diversity, efficiency, redundancy, and adaptability, reinforced using technology-based solutions such as intelligent infrastructure management systems, real-time data analysis, and advanced communication systems. The analysis of case studies confirmed that cities using smart city technologies cope better with crises, reducing their adverse effects and the time needed for recovery. The results also indicate that the integration of technologies requires a holistic approach, including the cooperation of different stakeholders, an appropriate regulatory framework, and systematic monitoring of the effects.
Originality /value: The study brings a new perspective to the literature by combining Smart City technologies with the concept of urban resilience. It offers a comprehensive approach to designing and implementing solutions that strengthen cities' resilience to various challenges.
Keywords: smart cities, urban resilience, smart city index.
Category of the paper: Research paper.

1. Introduction

In the face of dynamic climate change, rapidly developing urbanization, and increasing digitalization, cities worldwide face new challenges related to their resilience to crises. Natural disasters such as floods or hurricanes, power outages, cyberattacks, or sudden economic changes are just some of the threats that modern metropolisesIn this context, the concept of city resilience plays a key role, understood as the ability to adapt, respond, and return to balance after unforeseen disruptions. Modern cities are also witnessing the dynamic development of the Smart City concept. Smart City is not only the implementation of modern technologies such as the Internet of Things (IoT), Big Data, and artificial intelligence (AI) but also a comprehensive change in the way cities function. This concept aims to optimize urban resources, improve residents' quality of life, and increase operational efficiency. Smart City is not only about smart street lighting or traffic management applications - it is a complex network of systems and processes enabling a quick response to environmental, social, and technological changes. City resilience and Smart City are concepts that can complement each other. Integrating both approaches can improve cities' ability to anticipate, prevent, and respond to sudden disruptions. Rather than treating these concepts separately, cities are increasingly implementing strategies that combine resilience elements with Smart City technologies, allowing them to more effectively protect critical infrastructure, manage traffic, monitor air pollution, or respond to sudden weather changes. This article explores the interconnections between urban resilience and the Smart City concept. The article will discuss key definitions, theoretical foundations, implementation examples, and the main challenges and benefits of integrating these two concepts. It will also provide recommendations on how cities can increase their resilience by using Smart City tools to create more resilient, safe, and sustainable urban spaces.

2. Resilience and Smart City

The urbanization process in the 21st century brings increasing challenges for cities related to dynamic technological development, the growing intensity of climate change, extreme phenomena, and demographic pressure. In response to these challenges, two key concepts supporting the development and management of cities have been created—urban resilience and the idea of smart cities (Wardekker, 2020; Jiang, 2021; Shamsuddin, 2020). Both approaches combine modern tools and strategies to meet the challenges of modernity while differing in the scope of applications and the perspective of action.

2.1. Main assumptions of urban resillience

Resilience plays an increasingly important role in urban management, especially in global challenges such as climate change, natural disasters, and social and economic crises. Modern cities, as complex systems, must survive disruptions and quickly regenerate, adapt to new conditions, and implement lasting changes to increase their resilience for the future. Urban resilience is an interdisciplinary concept that integrates social, economic, environmental, and technological aspects to support cities in building lasting security and stability (Albino, 2015). The basic assumption of urban resilience is the ability of cities to absorb disruptions, quickly return to normal functioning, and transform their systems into more sustainable and resilient ones. Unlike traditional crisis management, which focuses on reacting to threats, urban resilience emphasizes anticipating, reducing risk, and implementing long-term strategies. The key pillars of this concept are resilience, regeneration, adaptation, and transformation (Ribeiro, 2019; Meerow, 2016; Büyüközkan, 2022). Resilience means minimizing disruptions' effects through strong infrastructure, efficient management, and effective support systems (Büyüközkan, 2022). Regeneration is the rapid restoration of full functionality after a crisis, which is possible thanks to effective response and recovery mechanisms. Adaptation refers to the ability to adapt to new conditions to avoid similar threats in the future. At the same time, transformation involves reorganizing urban systems towards more sustainable functioning. Urban resilience is multidimensional, covering various aspects of the functioning of cities. The physical dimension concerns urban infrastructure, including buildings, transport, energy, and water networks. It is crucial to design spaces that are resistant to floods, earthquakes, or other natural disasters. The economic dimension focuses on the stability of the local economy and the ability to maintain business in crises. The social aspect includes social cohesion, cooperation of residents, and the ability to cope with challenges together. The institutional dimension concerns the ability of public and private organizations to respond effectively to crises, as well as their ability to introduce structural changes. Contemporary approaches to urban resilience emphasize the concept's evolutionary nature, which goes beyond the traditional equilibrium model. Instead of restoring the city to its pre-crisis state, it aims to transform it to increase its capacity to cope with future disruptions. Assessing the resilience of cities is a key element of implementing this concept. It is often based on diagnostic tools and indicators such as the City Resilience Framework (CRF) developed by the Rockefeller Foundation. These indicators allow for the analysis of aspects such as critical infrastructure, the ability of communities to respond, and the flexibility of institutions. Modern tools such as GIS models enable detailed mapping of key areas vulnerable to hazards and spatial planning that considers resilience to different types of risks. However, the lack of uniform definitions of urban resilience and limited data availability make it difficult to accurately model and forecast resilience. In addition, each city has a unique set of challenges resulting from local conditions, which requires tailored solutions and strategies. Practical application of resilience Urban

resilience encompasses a wide range of activities in urban management. In spatial planning, it is crucial to design infrastructure that can withstand floods, earthquakes, or extreme weather events. Risk management focuses on creating effective crisis response strategies, such as evacuation plans or early warning systems. Adaptation to climate change requires investing in technologies that support sustainable development and reduce carbon dioxide emissions. Innovative approaches, such as developing smart cities, which use modern technologies to monitor and manage urban systems, are integral to resilience strategies. Examples of effective implementation of urban resilience can be found in cities such as Rotterdam, where innovative water management and flood protection solutions are developed, and in Singapore, where intelligent transport systems and energy management are invested. Other cities, such as Barcelona, combine resilience with improving the quality of life, creating spaces conducive to social cooperation and sustainable development. Such an approach not only allows for the protection of resources but also strengthens social cohesion and supports the development of local economies. Urban resilience is a dynamic concept that integrates diverse fields of knowledge and practice. It is the foundation for future-oriented urban management strategies, enabling cities to survive and thrive in the face of growing global challenges. In the context of intensifying climate change, increasing urbanization, and socio-economic tensions, urban resilience is becoming a necessity and an opportunity to introduce innovative solutions that will improve the quality of life of their inhabitants and ensure long-term environmental stability. Although the challenges related to implementing urban resilience are significant, they also offer enormous potential to transform cities into more resilient, sustainable, and welcoming spaces.

2.2. Smart city assumptions

The city concept is based on using modern information and communication technologies and innovative solutions to improve residents' quality of life, improve the management of urban resources, increase operational efficiency, and promote sustainable development. The essence of a smart city is integrating intelligent city management systems, such as IoT, big data, or advanced digital platforms, which enable monitoring of urban infrastructure and making better strategic decisions. A key aspect of this approach is supporting sustainable development by promoting ecological solutions, such as energy efficiency, renewable energy sources, or circular economy, which contributes to reducing CO_2 emissions and protecting natural resources (Ji, 2024; Tomadon, 2024).

The smart city also includes the development of smart infrastructure and urban mobility, which reduces traffic jams, improves public transport, and increases the availability of urban services. An essential element is the involvement of residents through the creation of participatory platforms that allow them to participate actively in decision-making processes, strengthening their influence on the development of cities. These activities lead to an improvement in the quality of life, both through better access to services and socio-economic integration (Shao, 2024).

The city concept is played by cooperation between the public, private, and civic sectors, which enables the effective implementation of projects and the achievement of strategic goals. Urban management in this model is based on indicators and standards that allow monitoring and evaluation of progress in implementing smart city initiatives. That makes adapting activities to local needs and avoiding implementation errors possible. The smart city also emphasizes building resilience in the towns to various types of crises, both environmental and social. By developing flexible adaptation strategies, cities can better respond to sudden events like natural disasters or economic crises. The effect of implementing the smart city concept is the improvement of the functioning of cities, reduction of operating costs, reduction of negative impact on the environment, and increase of the involvement of local communities in city management, leading to greater sustainability and inclusiveness.

3. Smart city elements in urban resilience

Resilience and the smart city concept are closely linked, as smart management technologies are a key tool supporting the development of urban resilience. Smart cities, thanks to the use of data, the Internet of Things (IoT), and artificial intelligence (AI), allow cities not only to function better daily but also to prepare for crises more effectively and respond to them faster and more efficiently (Allam, 2019). One of the most important areas in which the concept of urban resilience and smart cities should be considered is monitoring threats and responding in real time (Chen, 2020). Resilience is based on the city's ability to predict and react quickly to threats such as floods, earthquakes, air pollution, or power outages. The smart city concept uses sensor networks and data analysis systems that constantly monitor key aspects of the urban environment. For example, intelligent water management systems can detect a rise in water levels during heavy rainfall and automatically start pumps, preventing floods (Dai, 2024).

Crisis infrastructure management is another common ground between urban resilience and smart cities. Critical infrastructure, such as bridges, roads, water, and power networks, is crucial for the city's functioning. Smart cities enable ongoing monitoring of infrastructure conditions thanks to IoT sensors that collect data on their condition. In the context of resilience, potential problems, such as structural cracks or power grid overloads, are detected early, which helps prevent disasters and minimize losses. Smart cities implement intelligent power grids that optimize energy supply depending on demand. In a crisis, such as a power outage, these systems can redirect energy from alternative sources, such as solar panels or local generators. Thanks to this, the city maintains continuity of operation, a key element of resilience.

A resilient city must be able to maintain the efficiency of its transport system under challenging conditions. Smart cities implement intelligent transport systems that monitor traffic flow in real-time, report accidents, and redirect vehicles to alternative routes. Examples are

cities like Singapore, where dynamic traffic management prevents traffic paralysis in crises, such as during heavy rainfall (Omotayo, 2023).

Smart city elements are also used in water management and adaptation to climate change. Smart City allows for precise management of water resources, which is crucial in the face of growing climate threats. Thanks to IoT systems, cities can monitor river water levels, drinking water quality, or leaks in water supply networks. For example, Rotterdam has implemented water retention systems that collect excess water during heavy rains and use it during drought, increasing the city's resilience to climate change (Chen, 2020; Drodniak, 2018).

The relationship between resilience and smart cities is very closely visible in the communities and education. Community and education play a key role in integrating the concepts of urban resilience and smart cities. Including the community in city planning and management processes strengthens local resilience. This includes initiatives such as building support networks, holding joint workshops, and conducting public consultations (Wardekker, 2020). Communities with strong social ties are better prepared to deal with crises because they can more easily mobilize resources and share information. Thanks to mobile applications, residents can stay updated on threats such as approaching storms or air pollution. These technologies also enable residents to manage the city, e.g., by reporting infrastructure problems or co-creating local initiatives (Drobniak, 2018). Cooperation between schools, universities, and non-governmental organizations can create innovative projects supporting resilience (Amirzadeh, 2022). Integrating community and education within urban resilience and smart cities not only increases the resilience of cities to crises but also supports their sustainable development and improves the quality of life of their inhabitants.

Resilience and smart cities concepts in sustainable development and environmental protection are based on the synergy between technology, adaptability, and urban planning to increase cities' resilience to hazards and support long-term sustainability. The concept of smart cities combines information and communication technologies (ICT) with improving residents' quality of life and operational efficiency while considering future generations' environmental, social, and economic needs (Huovila, 2019). Urban resilience refers to the ability of cities to respond to hazards, absorb them, and adapt to changes such as climate change, urbanization, or economic shocks (Wardekker, 2020; Drobniak, 2018). Actions to build urban resilience cover different dimensions, such as environmental, economic, social, infrastructural, and institutional, which allows for better integration of sustainable development (Chen, 2020; Ribeiro, 2019).

Data analysis and prediction are the last level that can be considered for smart city and urban resilience. Smart city elements in urban resilience at the level of data analysis and prediction offer advanced tools for monitoring, managing, and planning the development of cities, taking into account their ability to respond to disruptions and changes. Urban resilience includes the ability of the town to absorb, adapt, and transform in the face of disruptions such as natural disasters, climate change, or social and economic crises. Contemporary models suggest that the integration of Smart City with resilience includes four pillars:

- adaptability - the city's ability to adapt to new conditions,
- resilience - the ability to minimize the impact of disruptions,
- recovery - the ability to quickly return to pre-disruption functions,
- transformation - the ability to change into a more resistant form (Chen, 2020; Vesalitskaya, 2019).

Smart Cities use advanced technologies such as IoT, Big Data, and AI to support resilience by:

- Real-time monitoring – e.g., GIS systems allow for the identification of areas susceptible to natural disasters (Sajjad, 2021).
- Modeling and simulations – e.g., predictive models forecast the effects of climate change and help develop adaptation plans (Chen, 2020).
- City indicators—Standard indicators for smart cities support the assessment of progress towards sustainable development (Huovila, 2019).

Resilience is increasingly essential in urban management, especially in global challenges such as climate change, natural disasters, and social and economic crises. Modern cities, as complex systems, must survive disruptions and quickly regenerate, adapt to new conditions, and implement lasting changes to increase their resilience for the future. Urban resilience is an interdisciplinary concept that integrates social, economic, environmental, and technological aspects to support cities in building lasting security and stability (Albino 2015). The basic assumption of urban resilience is the ability of cities to absorb disruptions, quickly return to normal functioning, and transform their systems into more sustainable and resilient ones.

4. Examples of smart city solutions in city resilience

Resilient cities using smart city technologies use advanced technological solutions to improve adaptability, crisis resilience, and the quality of life of their inhabitants.

One of the most advanced cities in the world in terms of using smart city technologies and building urban resilience is Rotterdam in the Netherlands. The city has created innovative solutions such as "Water Squares", which function as public spaces and water retention during floods. Rotterdam is implementing intelligent water level monitoring and risk forecasting systems to support flood protection. Integrated urban planning includes green areas and climate-resilient infrastructure, making Rotterdam a model for adaptation and sustainable urban development (Amirzadeh, 2022; Wardekker, 2020).

Another resilient city is Hong Kong. Hong Kong is a resilient Smart City that effectively copes with natural hazards thanks to advanced GIS technologies and intelligent resource management systems. The high density of development requires precise spatial planning, so the city has implemented digital solutions to monitor and analyze risks such as floods

and typhoons. Hong Kong also integrates transport and infrastructure systems to ensure greater resilience to crises, making it a model for other densely populated cities.

On the other hand, Vienna in Austria focuses on energy savings and emission reductions through programs such as the " Electric Mobility Program" and "Urban Heating and Cooling Program." The city has introduced green standards in public procurement and is becoming a global leader. Vienna integrates advanced technologies with climate policy, investing in modern infrastructure and green urban spaces. Thanks to these actions, the city strengthens its resilience to climate change. It improves the quality of life of its inhabitants, setting new standards in urban management and adaptation to future challenges.

A Polish city that is an example of urban resilience is Katowice. Katowice, especially the Załęże district, is an example of urban resilience in Poland, developed within the URBACT project "Resilient Europe". The city has implemented a local action program, combining Smart City technologies with adaptation to socio-economic challenges. Załęże integrates green spaces and an innovative approach to spatial planning, improving residents' quality of life. Katowice invests in crisis-resistant infrastructure and sustainable development, becoming a model for other European post-industrial cities. Thanks to strategic analysis and cooperation of the local community, the city builds resilience to changes and economic shocks, creating a sustainable future.

5. Conclusions

Integrating the Smart City concept with urban resilience is a key element of modern city management. It enables them to be better prepared for crises, respond faster to disruptions, and build long-term stability. Using advanced technologies such as the Internet of Things (IoT), real-time data analysis, or artificial intelligence, Smart City allows for more effective monitoring, management, and planning of urban spaces. Introducing such solutions helps improve the functioning of cities, increasing their ability to adapt and regenerate after crises and enabling transformation into more sustainable and resilient systems. A key aspect of urban resilience is its multidimensional nature, encompassing social, economic, environmental, and technological factors. Pillars such as resilience, regeneration, adaptation, and transformation are reinforced by innovative Smart City technologies, which enable ongoing monitoring of the condition of infrastructure, optimization of the management of urban resources, and faster response to unforeseen situations. By integrating solutions such as intelligent transport systems, energy networks, or water management systems, cities can more effectively minimize the effects of crises and reduce the time and costs of reconstruction. Examples of cities such as Rotterdam, Katowice and Singapore illustrate the potential of this integration in practice. Rotterdam has implemented intelligent water management systems

and solutions such as "Water Squares", which support water retention and protect the city from floods. As part of the URBACT project, Katowice combines Smart City technologies with local initiatives, improving residents' quality of life and strengthening social cohesion. In turn, thanks to advanced transport systems and innovative energy solutions, Singapore has become a model for other cities, effectively combining resilience and operational efficiency. Smart City and urban resilience are not free from challenges, such as the lack of uniform standards, limited data availability, or the diversity of local conditions. Nevertheless, their integration offers enormous potential for transforming cities into more resilient, sustainable, and friendly environments. In the era of climate change, urbanization, and growing socio-economic pressure, the development of these concepts is a necessity and an opportunity to improve residents' quality of life. In the future, further research and innovative implementations in Smart City and urban resilience can become the foundation for sustainable city management. The synergy between technology, urban planning, and social engagement will enable the creation of cities that not only effectively cope with current challenges but also build a safe and stable future for future generations.

References

1. Albino, V., Berardi, U., Dangelico, R.M. (2015). Smart cities: Definitions, dimensions, performance, and initiatives. *Journal of Urban Technology*, *22(1)*. Retrieved from: https://www.mendeley.com/catalogue/ce4d9c1a-be6e-3217-830c-c2aa0d894e0f/, 21.08.2024.
2. Almulhim, A.I., Cobbinah, P.B. (2024). Framing resilience in Saudi Arabian cities: On climate change and urban policy. *Sustainable Cities and Society*, *101,* doi:10.1016/j.scs.2024.105172.
3. Amegavi, G.B., Nursey-Bray, M., Suh, J. (2024). Exploring the realities of urban resilience: Practitioners' perspectives. *International Journal of Disaster Risk Reduction*, *103*, doi:10.1016/j.ijdrr.2024.104313.
4. Amirzadeh, M., Barakpour, N. (2021). Strategies for building community resilience against slow-onset hazards. *International Journal of Disaster Risk Reduction*, *66*, *102599*, doi:10.1016/j.ijdrr.2021.102599.
5. Amirzadeh, M., Sobhaninia, S., Sharifi, A. (2022). Urban resilience: A vague or an evolutionary concept? *Sustainable Cities and Society*, *81*, doi:10.1016/j.scs.2022. 103853.
6. Barata-Salgueiro, T., Erkip, F. (2014). Retail planning and urban resilience – An introduction to the special issue. *Cities*, *36*, pp. 107-111, doi:10.1016/j.cities.2013.01.007.

7. Büyüközkan, G., Ilıcak, Ö., Feyzioğlu, O. (2022). A review of urban resilience literature. *Sustainable Cities and Society*, *77*, *103579*, doi:10.1016/j.scs.2021.103579.
8. Chen, C., Xu, L., Zhao, D., Xu, T., Lei, P. (2020). A new model for describing the urban resilience considering adaptability, resistance and recovery. *Safety Science*, *128*, *104756*, doi :10.1016/j.ssci.2020.104756.
9. Coaffee, J. (2008). Risk, resilience, and environmentally sustainable cities. *Energy Policy*, *36(12)*, pp. 4633-4638, doi:10.1016/j.enpol.2008.09.048.
10. da Silva Tomadon, L., do Couto, E.V., de Vries, W.T., Moretto, Y. (2024). Smart city and sustainability indicators: A bibliometric literature review. *Discover Sustainability*, *5(1)*, pp. 1-21. Retrieved from: https://link-1springer-1com-1bnnegvla036f.han.polsl.pl/article/10.1007/s43621-024-00328-w, 5.08.2024.
11. Drobnik, A. (2018). Urban resilience programming – the example of the Załęże district in Katowice. *Scientific Works of the Wrocław University of Economics, No. 502,* doi:10.15611/pn.2018.502.02.
12. From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world— *ScienceDirect*. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S016920461100079, 7.09.2024.
13. Huang, G., Li, D., Zhu, X., Zhu, J. (2021). Influencing factors and their influencing mechanisms on urban resilience in China. *Sustainable Cities and Society, 74*, *103210*, doi: 10.1016/j.scs.2021.103210.
14. Huovila, A., Bosch, P., Airaksinen, M. (2019). Comparative analysis of standardized indicators for Smart sustainable cities: What indicators and standards to use and when? *Cities, 89,* pp. 141-153, doi:10.1016/j.cities.2019.01.029.
15. Jania, A. (2021). Diagnosing Urban Resilience in an Evolutionary Approach. *Acta Universitatis Lodziensis. Folia Oeconomica, 4(355)*, pp. 4-27, https://doi.org/10.18778/0208-6018.355.01.
16. Ji, X., Chen, J., Zhang, H. (2024). Smart city construction empowers tourism: Mechanism analysis and spatial spillover effects. *Humanities and Social Sciences Communications, 11(1)*, pp. 1-14. Palgrave, Downloaded January 3, 2025. Retrieved from: https://link-1springer-1com-1bnnegvla036f.han.polsl.pl/article/10.1057/s41599-024-03626-w
17. Jiang, H., Jiang, P., Wang, D., Wu, J. (2021). Can smart city construction facilitate green total factor productivity? A quasi-natural experiment based on China's smart city pilot. *Sustainable Cities and Society, 69, 102809*, doi:10.1016/j.scs.2021.102809.
18. Meerow, S., Newell, J.P., Stults, M. (2016). Defining urban resilience: A review. *Landscape and Urban Planning, 147,* pp. 38-49, doi :10.1016/j.landurbplan.2015.11.011.
19. Palakhamarn, T., Kamolvej, T. (2024). Revitalizing Urban Resilience in Thailand: Exploring Conceptual Frameworks and Terminology. *Journal of Architectural/Planning Research and Studies, 21(2),* pp. 263-282, doi:10.56261/jars.v21.262070.
20. Ribeiro, P.J.G., Gonçalves, L.A.P.J. (2019). Urban resilience: A conceptual framework.

Sustainable Cities and Society, *50*, doi:10.1016/j.scs.2019.101625.

21. Sajjad, M., Chan, J.C.L., Chopra, S.S. (2021). Rethinking disaster resilience in high-density cities: Towards an urban resilience knowledge system. *Sustainable Cities and Society, 69, 102850*. doi:10.1016/j.scs.2021.102850.
22. Shafiei Dastjerdi, M., Lak, A., Ghaffari, A., Sharifi, A. (2021). A conceptual framework for resilient place assessment based on spatial resilience approach: An integrative review. *Urban Climate, 36*, *100794*, doi:10.1016/j.uclim.2021.100794.
23. Shamsuddin, S. (2020). Resilience resistance: The challenges and implications of urban resilience implementation. *Cities, 103*, doi:10.1016/j.cities.2020.102763.
24. Shao, H., Tang, X., Xiao, X., Ma, Y., Lin, Z. (2024). Can Smart city policies enhance corporate environmental performance? Evidence from China. *Environment, Development and Sustainability*, pp. 1-32. https://link-1springer-1com-1bnnegvla036f.han.polsl.pl/article/10.1007 /s10668-024-05427-2, 5.08.2024.
25. Sharifi, A., Yamagata, Y. (2014). Resilient Urban Planning: Major Principles and Criteria. *Energy Procedia, 61*, pp. 1491-1495, doi:10.1016/j.egypro.2014.12.154.
26. Wang, W., Wei, H., Hassan, H., He, X. (2024). Research progress and prospects of urban resilience in the perspective of climate change. *Frontiers in Earth Science, 12*, doi:10.3389/feart.2024.1247360.
27. Zeng, X., Yu, Y., Yang, S., Lv , Y., Sarker, M.N.I. (2022). Urban Resilience for Urban Sustainability: Concepts, Dimensions, and Perspectives. *Sustainability*, *14(5)*, doi:10.3390/su14052481.

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THE CONCEPT OF SMART VILLAGES – ITS DEVELOPMENT OPPORTUNITIES, PROSPECTS AND CHALLENGES

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Purpose: This article aims to present the concept of Smart Villages as a modern approach to rural development that integrates information and communication technologies, innovative solutions, and active involvement of local communities. The article analyses the possibilities of developing Smart Villages in the context of Polish realities, considering their potential for sustainable development, improving residents' quality of life, and strengthening the local economy. At the same time, the challenges and limitations that may accompany implementing this concept in practice will be reflected.

Design/methodology/approach: The article uses an approach based on literature analysis, case studies, and available empirical data. A literature review on the Smart Villages concept and its application in various international contexts was conducted in the first stage. Then, examples of implementations of this concept in Poland and other countries were analyzed, identifying key success factors and implementation barriers. In order to better understand local realities, statistical data on rural areas in Poland and the results of previous studies on the level of digitalization and involvement of local communities were used. The entire analysis was supplemented with a reflection on the development prospects of this concept in the context of Polish reality.

Findings: The Smart Villages concept has significant potential for transforming Polish rural areas through integrating modern technologies, developing sustainable initiatives and increasing local community involvement. The implementation of smart solutions contributes to the improvement of digital infrastructure, which allows residents to have better access to education, remote work and health services, such as telemedicine. Initiatives related to renewable energy sources and environmental protection support the sustainable development of local communities while generating savings and improving the quality of life. In agriculture, innovative technologies, such as the Internet of Things or precision farming, increase production efficiency and enable better resource management. The analysis also showed that engaging residents in decision-making processes and implementing smart projects strengthens social capital and contributes to the activation of local communities.

Originality/value: The originality and value of the article result from the comprehensive approach to analyzing the Smart Villages concept in the context of Polish socio-economic reality. In contrast to previous studies, which often focus on large smart city projects, the article focuses on rural areas' unique challenges and opportunities, offering a new perspective on their development. The presented conclusions can be a valuable source of knowledge for policymakers and practitioners implementing smart solutions locally. Additionally, the article

indicates the importance of social participation and innovative technologies in building more sustainable and resilient rural communities, which can contribute to creating coherent regional development strategies.
Keywords: smart villages, smart city.
Category of the paper: Research paper.

1. Introduction

Modern rural areas, especially those aspiring to be called "Smart Villages", have faced challenges of an unprecedented scale and complexity. Global climate change, depopulation of rural areas, dynamic technological development, and the need to ensure residents' safety and high quality of life require innovative solutions in crisis management. Crises such as natural disasters, epidemiological threats, or infrastructure problems reveal the weak points of traditional management systems while creating space for the implementation of advanced technologies and new organizational models. The literature (Wolski, 2018; Kalinowski, 2021; Howard, 2023; Emerllahu, 2024) on the subject increasingly indicates that the key to effective crisis management in Smart Villages is the integration of information and communication technologies (ICT) with traditional management strategies. Such solutions include real-time monitoring systems, using artificial intelligence to predict and model crises, or creating platforms supporting cooperation between various entities. However, despite significant technological progress, many villages still struggle with the lack of a coherent strategy integrating these innovations into everyday functioning (Wolski, 2018; Kalinowski, 2021).

This publication examines modern technologies' role in crisis management in smart villages. It is based on a case study analysis of selected Smart Villages that have successfully implemented advanced crisis management systems.

The first part of the article presents the conceptual foundations of the Smart Villages concept . It discusses the genesis of the creation and assumptions of the Smart Villages concept. The second part of the article includes examples of using smart solutions in villages, including Finnish, Danish and Polish ones. A contemporary approach to crisis management in Smart Villages requires a view beyond the traditional management framework. A holistic approach is necessary, which considers both technological, social, and organizational aspects. This publication combines these elements into a coherent narrative that can serve as a basis for further research and practical implementations. In an era of increasingly frequent and complex crises, developing and implementing smart solutions is becoming a challenge and necessary for building safe and resilient villages of the future.

2. The origins of the concept of the smart village

The origins of the Smart Village concept are rooted in dynamic socio-economic and technological changes that have highlighted the challenges facing rural areas, such as depopulation, limited access to public services, and growing digital exclusion. Figure 1 shows population migration in Poland in 2019. The figure shows the spatial distribution of population migration in Poland at the municipal level, showing a clear differentiation between regions regarding net migration. Blue indicates areas with a positive migration balance, where more people arrive than leave a given municipality. That applies mainly to economically developed regions that are attractive regarding work, education, or quality of life, primarily around large cities such as Warsaw, Krakow, Wrocław, Poznań or Gdańsk. This phenomenon reflects the suburbanization process, in which people move to the suburbs of large cities agglomerations.

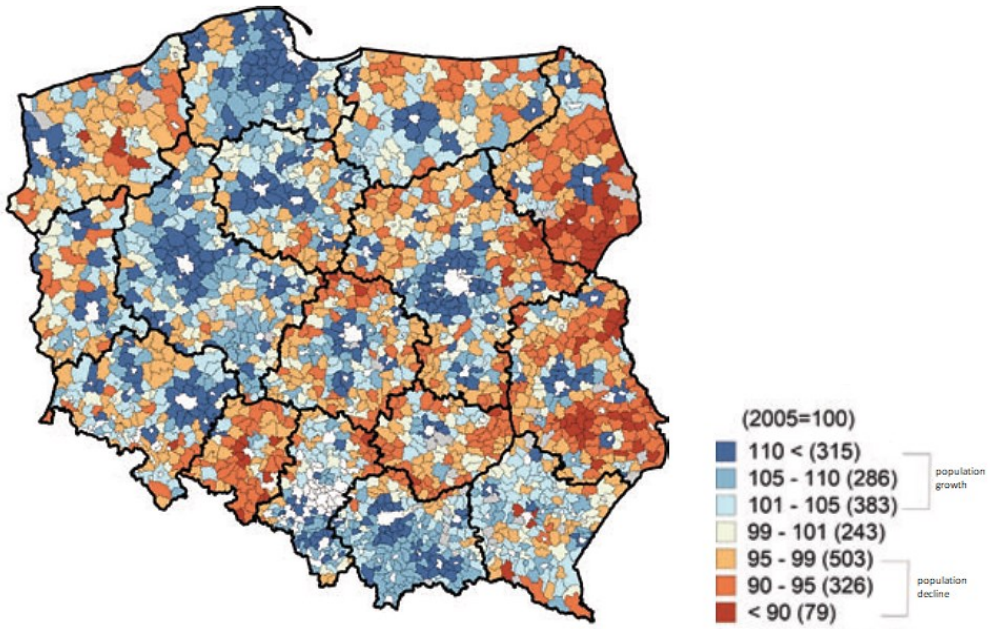

Figure 1. Migration of the Polish population.

Source: Wolski, 2018; Kalinowski, 2021.

In turn, the orange and red colors symbolize areas with a negative migration balance, i.e., places where more people leave than settle. That applies primarily to peripheral regions, rural areas, and those with limited development opportunities, evident in the east and northeast of Poland. Migrations from these areas are often motivated by the search for work or better living conditions in larger urban centers or abroad. The map's general picture shows dynamic urbanization and suburbanization processes, accompanied by the depopulation of less developed rural and peripheral areas, emphasizing spatial disproportions in the country's development. The concept of Smart Villages is an attempt to stop the migration of people from rural areas. This concept arose from the search for solutions enabling the sustainable development of rural regions and integrating their inhabitants within the global economy and

information society. The concept of a smart village was introduced to the public debate, particularly by the European Union. The 2017 EU Action for Smart Villages document defined them as communities using digital technologies and innovations to improve the quality of life, optimize public services, and effectively manage local resources (Wolski, 2018; Kalinowski, 2021). That was a response to challenges such as depopulation and marginalization of rural areas and the need for a more flexible and locally adapted approach to development (Kalinowski, 2021). Earlier studies and models from other regions inspired the European concept of smart villages. In particular, in India in 2010, scientists N. Viswanadham and Sowmya Vedula developed a model of smart villages as ecosystems integrating technological, natural and social resources. This model assumes that innovative management and the use of local potentials can lead to the self-sufficiency of villages and improve the quality of life of their inhabitants (Bokun, 2023; Lakshmanan, 2022). In the European context, the development of the Smart Village concept was related to the evolution of rural policy, which was moving away from a centralized management model towards a bottom-up approach, with greater involvement of local communities. In particular, information and communication technologies (ICT) were emphasized as a tool to eliminate differences between cities and villages. ICT allowed for improved access to education, health care, and public services and for integrating villages with socio-economic networks at the national and international levels (Bokun, 2023; Zavratnik, 2020). This concept was also shaped by global challenges, such as demographic changes, the need for energy transformation, or the implementation of sustainable development goals (SDGs). The implementation of Smart Villages has been recognized as a tool to achieve these goals more effectively, especially in areas such as eliminating poverty, improving access to education and promoting a low-emission economy (Wolski, 2018).

Contemporary Smart Villages are, therefore, a response to the challenges of the modern world by combining modern technologies with local potential, activating communities, and promoting sustainable development. This model is increasingly being adopted in various regions, adapting to specific cultural and geographical conditions (Emerllahu, 2024; Lučan, 2024).

3. The idea of a smart village

The village concept is a modern approach to rural development based on the use of digital technologies, innovations, and the involvement of local communities to improve the quality of life, increase the efficiency of public services, and sustainable resource management. Smart Village is based on integrating digital technologies and innovations with local initiatives to improve residents' quality of life, optimize public services, and effectively use local resources. In this approach, local communities play a key role in defining their needs and

challenges, giving projects a bottom-up character. Unlike traditional village development methods, Smart Village emphasizes the integration of modern technologies with the unique needs of local communities, creating models based on cooperation, flexibility, and sustainability. The basic idea of Smart Village is to enable rural communities to fully use their potential by introducing digital solutions that can improve access to services, education, health care, or the labor market. Thanks to information and communication technologies (ICT), such as the Internet of Things (IoT), big data, or mobile applications, villages can become more self-sufficient and better integrated with regional and global networks. A key element of this concept is supporting sustainable development, which means protecting the environment, using energy efficiently, and supporting the local economy based on ecological and innovative solutions.

Examples of Smart Villages implementation include various projects adapted to the specific needs of a given region. In Indonesia, digital rural information systems are being implemented, enabling better organization of local government work and residents' access to key data and public services (Aziiza, 2020; Zavratnik et al., 2020).

In Europe, Smart Villages focus on aspects such as developing local markets, digitalizing education and health care, and sustainable agriculture. In Poland, examples include projects related to renewable energy, the construction of smart infrastructure, and the development of e-government services (Wolski, 2018; Lee, 2024). One of the key challenges in implementing Smart Villages is the availability of technology. Many rural regions lack appropriate digital infrastructure, such as fast internet or energy systems supporting information technologies. Another problem is the development of digital competencies among residents, which requires educational support and appropriate training (Emerllahu, 2024; Gerli, 2022). However, Smart Villages are not just about technology. The essence of this idea is also building social ties, strengthening the sense of community, and promoting grassroots activities that consider local needs and traditions. A key element is the involvement of residents in the decision-making process, which leads to greater acceptance and durability of the implemented solutions (Manapa Sampetoding, 2024; Lučan, 2024).

4. Examples of using the Smart Villages concept

Smart Villages is a concept that is gaining importance in developing rural areas, especially in Poland, where a significant part of society lives in the countryside. The idea of Smart Villages is to use modern technologies, social innovations, and sustainable practices to address problems such as depopulation, limited access to public services, or economic inequalities. The aim is to improve residents' quality of life and ensure the sustainable development of rural areas. One of the applications of digital technologies is the Internet of Things. The use of the Internet

of Things in agriculture has promising prospects. Thanks to the collection and analysis of data, farmers can plan processes related to the cultivation and harvesting of crops much more precisely, while optimizing cooperation with the recipients of their products.

Additionally, machine learning algorithms allow the development of more effective cultivation methods, increasing the efficiency and sustainability of production. The Internet of Things can also be used in medical and uniformed services. There are many applications of digital technologies in villages. However, smart villages are not only digital services but, above all, people and their involvement in the development of the local community.

Malaysia can boast of using digital technologies, and over 20 modern villages have been created. In these villages, it was decided to fight poverty by building cheap, modern houses, providing education, and optimizing farms. Ultimately, this resulted in a threefold increase in the village population's income.

Finland has been implementing the Smart Villages concept for a dozen or so years now. In 2008, the first national strategy for fast broadband Internet in rural areas was implemented. Finland is a country where the Smart Village movement met with a very positive response due to the long tradition of local activity. In 1997, SYTY (Finnish Village Activities Association) was established. Eskola is one of the Finnish villages considered to be the forerunner of the smart ideology. Eskola is a small village of about 400 inhabitants, focusing on development and self-sufficiency while providing residents with access to key public services. Despite the challenges related to limiting these services, it was possible to establish Eskola Village Service Ltd., associating with 130 shareholders and employing seven people. The company conducts various activities, including kindergarten, dinner service, kiosk, home services, library and an application that enables vehicle rental. As part of an innovative approach to education, the primary school (grades 0-6) in Eskola is run by the Lapinjärvi municipality, 500 km away, as part of a three-year experiment. Thanks to digital solutions, Eskola residents can access public services, making the village an example of modern, sustainable development in rural areas.

Despite the lack of a formal legal and strategic framework for developing smart villages in Montenegro, it is possible to rely on the "Smart Specialization Strategy of Montenegro 2019-2024". The Smart Villages concept is still at an early stage of development, and the lack of appropriate regulations, financial incentives, and legal support makes its implementation difficult. Nevertheless, some initiatives support the development of this idea. Examples are the activities of the Ministry of Economy, the UNDP initiative's energy efficiency activities, and the implementation of the LEADER approach. An important undertaking is the Technopolis initiative, which aims to strengthen cross-border innovation networks through the Fertilization Innovation Laboratories in the agri-food sector, which allows for better linking of research with the activities of small and medium-sized enterprises. Another important project is the FILA Innovation Lab, which supports the development of smart solutions for agriculture, agricultural producers, and villages, focusing on implementing modern technologies.

An interesting example of the use of technology is the website www.seljak.me, which is the platform of the first digital village in Montenegro. It enables contact between farmers and potential consumers, providing a fast flow of information and offering the most extensive online offer of products and services in nine categories. The site also includes an educational section "farmer.me/ tips", which provides information materials from the world of agriculture. This initiative has enabled innovative solutions such as calving sensors, GPS collars for monitoring livestock, and bee sensors, which are examples of the effective digitalization of agriculture in Montenegro.

Denmark is another country that can boast a very dynamically developing concept of Smart Villages. An example is the village of Ryslinge. The village of Ryslinge, located in the municipality of Faaborg-Midtfyn, has shown dynamic development over the past five years. Thanks to local initiatives, 28 new jobs and three companies have been created there, and the number of residents has increased by 20-25 people per year during this period. To support settlement, the local council has appointed community ambassadors to promote the business offer and the possibility of settling in Ryslinge. The village currently has around 1700 inhabitants. In turn, Gludsted, a village in the municipality of Ikast-Brande, has taken decisive steps to counteract its potential depopulation, implementing activities under the slogan "Effort is useful." Thanks to the involvement of the local community, a kindergarten and a grocery store have been maintained, and free schools and large building plots have been created. Despite its small size – only around 300 inhabitants – Gludsted has retained key functions that have enlivened local community life.

A Polish example of Smart Village activities undertaken in Polish villages is the village of Ostoja (Olsztynek commune, Warmian-Masurian Voivodeship). The village of Ostoja implements the idea of Smart Village as an innovative agricultural ecosystem of the future, combining traditional methods with modern technologies. The aim is to create self-sufficient and ecological solutions that support sustainable agriculture, production, and life in rural areas. Key activities include implementing ecological agricultural practices, such as crop rotation, natural fertilization, and permaculture cultivation methods. A seed bank and a nursery of organic plants are being created in Ostoja to support local farmers in producing organic food. Precision farming technology automates and supports the processes, increasing crop efficiency and quality. An important element is using renewable energy sources, such as biogas plants, solar panels, and biomass, which is part of the 360 farm model - a closed resource circulation system. Waste-free, self-sufficient village settlements are also being created, combining modern construction solutions with traditional materials, such as moon wood. Product distribution is based on an innovative "farm-to-table" platform, enabling online ordering of fresh food. Ostoja is also developing an educational system that promotes ecology among children, youth, families, and professionals. Education is supported by Ostoja Natury TV, which popularizes ecological knowledge and traditional crafts. The village is involved in recreating traditional professions, such as beekeeper and blacksmith, and promotes local products.

Similarly, in the village of Piaseczna Górka, which implements the Smart Village concept (Morawica commune, Kielce district, Świętokrzyskie province). The commune implements innovative projects supporting sustainable development and social integration. In 2017, a rain garden was created, improving rainwater retention and supporting biodiversity and public space aesthetics. Autonomous solar lamps were also installed, illuminating sports and recreational infrastructure. In 2018, an outdoor library was created in a replica of a telephone booth, promoting reading and bookcrossing, and a questing path, combining historical education with entertainment. In addition, residents use a Facebook group, which improves communication and social consultations.

Another village that can be a Polish example of a smart village is Mniszek (Dragacz commune, Kuyavian-Pomeranian Voivodeship). Since 2011, over 40 projects have been implemented in the village, including intergenerational workshops, programming, robotics, 3D printing classes, handicrafts, and culinary workshops. An important achievement was establishing a village community center as an education and integration center, where cultural events, training, science festivals, and classes for children and adults are organized. Implemented projects, such as digitization of local history, ecological and artistic workshops, and activities for a healthy lifestyle, have contributed to the development of the community and increased awareness of residents. Mniszek is also distinguished by cultivating tradition, e.g. through workshops related to the culture of Kociewie, handicraft and regional cuisine. The village focuses on innovation, including digital development, organizing classes using modern technologies, and creating websites. Projects such as "Books Connect Generations" or "Detectives on the Trail of Science" integrate the community and educate interestingly.

5. Conclusions

The conclusions from the Smart Villages concept analysis indicate that this model can significantly contribute to the development of rural areas in Poland, responding to contemporary demographic, economic, and environmental challenges. Thanks to the integration of modern technologies, such as the digitization of public services and the use of renewable energy sources, Smart Villages offers solutions that improve residents' quality of life and increase the attractiveness of rural areas. This model supports sustainable development, reduces digital and spatial exclusion, and promotes social innovations that strengthen the local economy and social ties. The key element of success is the involvement of local communities in the decision-making process and cooperation with the public and private sectors. At the same time, implementing the Smart Villages concept requires overcoming significant barriers, such as the lack of appropriate digital infrastructure, limited technological competencies of residents, and difficulties in obtaining financing. In Poland, the development of Smart Villages

is not only a chance to solve problems related to the depopulation and marginalization of rural areas but also a way to use the potential of local communities and traditions in a modern, innovative way. A coherent support strategy at the national and regional level, including the effective use of European funds, is of key importance for the success of this concept. The development of Smart Villages can be an important step towards harmoniously combining sustainable development, environmental protection, and improving the quality of life in rural areas.

References

1. Aziiza, A.A., Susanto, T.D. (2020). The Smart Village Model for Rural Area (Case Study: Banyuwangi Regency). *IOP Conference Series: Materials Science and Engineering, 722(1)*. Retrieved from: https://doi.org/10.1088/1757-899X/722/1/012011.
2. Defe, R., Matsa, M. (2024). The significance of stakeholder engagement towards building sustainable climate-smart villages in Mwenezi District. *Environmental Challenges, 14*. Retrieved from: https://doi.org/10.1016/j.envc.2024.100855.
3. Distefano, C., Zhu, M., Mîndrilă, D. (2009). Understanding and Using Factor Scores: Considerations for the Applied Researcher – Practical Assessment. *Research & Evaluation, 14.*
4. Emerllahu, V., Bogataj, D. (2024). Smart Villages as infrastructure of rural areas: Literature review and research agenda. *IFAC- PapersOnLine, 58(3)*, pp. 268-273. Retrieved from: https://doi.org/10.1016/j.ifacol.2024.07.162.
5. Ezquerro, L., Coimbra, R., Bauluz, B., Núñez- Lahuerta, C., Román-Berdiel, T., Moreno-Azanza, M. (2024). Large dinosaur egg accumulations and their significance for understanding nesting behavior. *Geoscience Frontiers, 15(5)*. Retrieved from: https://doi.org/10.1016/ j.gsf.2024.101872.
6. Kalinowski, S., Komorowski, Ł., Rosa, A. (2021). *The concept of smart villages: Examples from Poland.* Warszawa: Institute Development Rural and Agricultural Sciences PAN. Retrieved from: https://doi.org/10.53098/9788389900623.
7. Lučan, J., Pokmajević, M., Kunčič, U. (2024). Impact of Technology on the Quality of Life of Elderly People in Smart Villages: Literature Review. *IFAC- PapersOnLine, 58(3)*, pp. 262-267. Retrieved from: https://doi.org/10.1016/j.ifacol.2024.07.161.
8. Manap Sampetoding, E.A., Er, M. (2024). Digital Transformation of Smart Village: A Systematic Literature Review. *Procedia Computer Science, 239,* pp. 1336-1343. Retrieved from: https://doi.org/10.1016/j.procs.2024.06.304.
9. Omotayo, A.O., Omotoso, A.B. (2025). Climate-smart agricultural technology and gender-differentiated food and water security: Evidence from smallholder sunflower (Helianthus

annuus L.) Farmers. *Agricultural Water Management, 308, 109276*. Retrieved from: https://doi.org/10.1016/j.agwat.2024.109276

10. Ostaszewski P. *Ostoja wioska 3.0.* Retrieved from: https://smart.irwirpan.waw.pl/pdf/Piotr%20Ostaszewski_Ostoja%20Wioska%203.0.pdf, 20.07.2024.
11. Shahzad, M.F., Xu, S., Lim, W.M., Yang, X., Khan, Q.R. (2024). *Artificial intelligence and social media on academic performance and mental well-being: Student perceptions of positive impact in the age of smart learning*. Retrieved from: https://doi.org/10.1016/j.heliyon.2024.e29523.
12. Tavakol, M., Wetzel, A. (2020). Factor Analysis: a means for theory and instrument development in support of construct validity. *International journal of medical education, Vol. 11,* pp. 245-247, Retrieved from: https://doi.org/10.5116/ijme.5f96.0f4a.
13. Wan, S., Zhang, P., Chen, S., Yang, Y. (2025). Digital village construction and depressive symptoms in rural middle-aged and older adults: Evidence from China. *Journal of Affective Disorders, 372,* pp. 200-209. Retrieved from: https://doi.org/10.1016/j.jad.2024.12.026.
14. Zavratnik, V., Podjed, D., Trilar, J., Hlebec, N., Kos, A., Duh, E.S. (2020). Sustainable and community-centered development of smart cities and villages. *Sustainability*, *12(10)*. Retrieved from: https://doi.org/10.3390/SU12103961.
15. Zhang, W., Xu, M., Feng, Y., Mao, Z., Yan, Z. (2024). The Effect of Procrastination on Physical Exercise among College Students—The Chain Effect of Exercise Commitment and Action Control. *International Journal of Mental Health Promotion, 26(8),* pp. 611-622. Retrieved from: https://doi.org/10.32604/ijmhp.2024.052730.

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THE IMPACT OF COVID-19 PANDEMIC ON THE USE OF ARTIFICIAL INTELLIGENCE IN THE FINANCIALIST AND ACCOUNTANT PROFESSION

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Purpose: The constant evolutionary processes taking place in the economy are stimulating economic development, as well as social and environmental, thus requiring the use of new IT solutions in the enterprise. The aim of the article is the use of modern technology in the work of the financier and to present what benefits and risks their use brings. The COVID-19 Pandemic has had a major impact on the development of modern technologies. Currently, companies are introducing artificial intelligence to automate processes in the work of the accountant and financier and to reduce the cost of the company. Through the use of modern technology, companies can facilitate and speed up the process of aggregating data, checking financial statements, and generating detailed analysis, and more quickly identify the risks to which the business unit is exposed. The article is a research study. In order to examine more deeply how modern technologies are used in business units, a survey was conducted among employees of various companies working in financial and accounting departments. The survey covered 2000 respondents. All the surveyed employees are simultaneously students at one of the three economic universities: in Krakow, Wroclaw and Katowice. The study is in line with the author's scientific interests

Design/methodology/approach: The research methods used are based on the study of the literature on the subject of research and conducting a survey in order to determine whether modern technologies have been introduced in the surveyed companies in order to simplify and automate the work process of a financier and accountant. The survey was also aimed at diagnosing what modern technologies have been introduced in the surveyed units and what advantages and threats are brought by the use of modern technologies in business units.

Findings: The implementation of modern technologies is essential for the proper functioning of every modern enterprise. In summary, any growing finance division is currently facing many challenges in implementing modern technologies into daily processes. They have great potential to support the work of accountants and financiers, but their effective use requires consideration of a variety of aspects, including issues related to data security, regulatory compliance and the development of professional competence.

Originality/value: The results of the survey are an important contribution to the discussion on the use of modern technologies in the work of a financier in the digital era and allow for a better understanding of the needs and expectations of practitioners in this field. Companies can effectively use modern technologies to optimize processes and increase the efficiency and precision of financial data analysis by using AI-based tools to automate routine tasks, identify

patterns and irregularities in data, and use advanced data analysis algorithms to generate more precise and comprehensive reports. The possibility of continuous development of data analysis algorithms, the development of machine learning technology and the growing understanding of the potential of artificial intelligence is still a topic that is still relevant and worth in-depth research.
Keywords: ERP, BI, new technologies, IT solutions, COVID-19 Pandemic, financial reports, accountant profession.
Category of the paper: Research paper.

1. Introduction

In the modern digital age and current economic realities, all financial departments in a company when conducting economic analysis and when making decisions should take advantage in the development of new technologies and the development of technology (Sierpińska, Jachna, 2004).

The participation of new technologies in the work of the financier is increasingly making its presence felt, and the process of digitalization is beginning to affect more and more activities (Talar, 2021). The use of new digital solutions is a source of many opportunities, and on the other hand, it poses many challenges for controlling units.

However, the introduction of new technologies seems inevitable, mainly to keep pace with technological developments, to streamline processes and data flow in the company and to meet customer expectations.

The main purpose of the chapter is to look at the prospect of improving the work of a financier in the context of technological advances, which is certainly the impact of modern technology. The research method used is an in-depth analysis of the literature and a discussion of the results of the scientific study conducted. Taking into account the issues presented above, the research problem of this work can be formulated in the form of the following questions: Is modern technology helpful in the activities undertaken by financiers and accountants? What risks and benefits does it bring? What risks and benefits does it bring? What are the main challenges of adapting modern technology in the work of a financier, while maintaining data security, compliance with regulations and the need to develop the professional competence of employees?

2. The COVID-19 Pandemic and its impact on the development of modern technology

The COVID-19 Pandemic has had a tremendous impact on the development of modern technology, accelerating many trends that had previously developed slowly. Faced with a global health crisis, companies and institutions have had to adapt to new conditions, prompting them to invest in innovation. A rapid increase in the number of people testing positive worldwide prompted the World Health Organization (WHO) to declare COVID-19 an epidemic on January 31, 2020, and then classify it as a pandemic on March 11, 2020 (Bialas, Emerling, 2022; Maier, Brockmann, 2020; Conway, 2023). The COVID-19 pandemic that we faced had very negative consequences not only in the sphere of social life, but also in the sphere of economic life. The governments of many countries, in order to protect their citizens, introduced lock downs and bans on travel, assembly and many other restrictions. It is estimated that these restrictions have affected about 90% of the world's population (Gossling, Scott, Hall, 2020). Radical restrictions imposed by individual countries have contributed to a significant reduction in consumption, except for food purchases, for example. In addition, production at factories has been severely curtailed due to worker illnesses, contributing to disruptions in global supply and contributing to production delays in international markets. (https://www.weforum.org/…, 2020). All these restrictions in public life have affected the development of various areas of innovation.

One of the most important areas of innovation has been digitization. Many companies have moved their operations to the Internet. Remote working has grown in popularity, which in turn has contributed to the development of online working tools. Applications such as Zoom, Microsoft Teams and Click Meeting became essential components of professional business meetings and conferences. Companies began to invest in technologies for effective communication and collaboration. The pandemic also accelerated the development of artificial intelligence and data analysis. Companies began to use AI for analytics. Finally, the pandemic highlighted the importance of cyber security. The increase in hacking attacks and data theft forced organizations to invest in security. Increased awareness of threats has made data protection a priority.

In conclusion, the COVID-19 pandemic helped accelerate the development of modern technologies in many fields, which affected daily life after the pandemic.

3. The importance of artificial intelligence in the finance profession

Today's business challenges and also pandemic have forced businesses to implement modern technology platforms. Accounting software or any other solution supporting the organization of a company's finances must adapt to the changing needs of information management. In the field of accounting services, there is a growing trend of greater awareness among executives, according to which the books of account are an indispensable working tool not only for accountants, but also for the board of directors and management - executives. Accordingly, the coordination of accounting processes must be based on the full timeliness of data, its error-free and wider availability (Rzepecka,2019).

Consequently, modern technologies such as artificial intelligence, Big Data analytics, process automation and blockchain technology are an integral part of the modern financier. They are fundamentally changing the way managers collect, analyze and interpret financial data, allowing them to detect anomalies and identify risks more quickly and accurately (Borowiec, 2022). Particularly important is the role of artificial intelligence, which enables in-depth analysis based on large data sets, leading to streamlined processes and reduced risk of human error (Kokina, Blanchet, 2019).

Examples of processes that use modern technology include:

- circulation of supplier invoices - according to predetermined rules, computer programs enable seamless registration of supplier invoices and automatic assignment of them to the appropriate people in the company. Once accepted, the process moves to automatic decreeing, and then the invoices are assigned to the place of cost generation (MPK);
- verification of financial data - RPA technology can be used to check financial data such as account balance, taxpayer identification number, bank account or invoice payment receipt;
- payroll accounting - robots are responsible not only for creating payrolls, issuing PFRON deductions and certificates for employees, but also for downloading exemptions from ePUAP and accounting for employee absences;
- order processing - the programs have the ability to record orders, automatically generate invoices and post them, and monitor the payment process of payables. They can also retrieve bank statements and send reminders for outstanding payments;
- financial reporting - RPA bots allow companies to quickly create financial reports by importing spreadsheets from a variety of sources, allowing access to a full range of accounting-related data and the use of reconciliation tools.

It is also assisted by OCR (Optical Character Recognition) technology, which can read data from different types of letters, such as purchase orders and invoices, enabling automatic data entry into the system (https://www.enova.pl/…).

ERP software also plays a very important role in the work of an accountant and financier. ERP (Enterprise Resource Planning) software offers a comprehensive business management solution that integrates various business processes into a single system. It not only handles finances, but also production, sales, logistics and human resources processes. The ERP system provides a holistic view of a company's processes and data, enabling informed decision-making. It is more comprehensive and designed for larger companies that require an integrated approach to managing all aspects of their business. On a smaller scale, advanced accounting systems also demonstrate these functions.

The primary difference between accounting systems and ERP software lies in their scope and focus. The former are specifically designed for financial management, while the latter offers a wider range of business process management capabilities. This means that an ERP system will typically have more extensive operational management and financial management functions. The advantages and disadvantages of implementing an ERP system are shown in the table below.

Table 1.
Selected advantages and disadvantages of implementing an ERP system

Disadvantages of ERP systems	Advantages of ERP systems
- high cost of license purchase - very expensive implementation and adaptation of the system to the specifics of the company - serious organizational and process changes inside the company forced by the system implementation - high level of complexity of the system - difficulty to adapt it to processes functioning in the company - protracted implementation process and lack of clear date defining its end	- integration of all processes, including production and administration of its own database for individual processes - improvement of communication between the company's business partners - such systems can also be a strategic competitive advantage

Source: own elaboration based on: Koliński, Stajniak, 2018, p. 25.

Accounting systems tend to be more flexible, allowing companies to tailor them to their specific needs. ERP systems, while usually somewhat rigid, offer a more streamlined and organized approach to managing business processes.

Accounting systems are less expensive and through this more accessible, especially for smaller companies or those with limited budgets. They are also traditionally easier to set up and use compared to ERP systems. However, the advent of Software as a Service (SaaS) solutions has made ERP platforms much easier to run than they were just a few years ago.

What's more, ERP systems can increase data security by centralizing all information within a company, making it easier to secure and protect it from unauthorized access. This is especially important for companies that process sensitive financial data.

ERP systems can also help companies reduce IT costs and streamline operations, and eliminate the need for multiple separate solutions, leading to lower IT costs. Advanced features such as intelligent process automation also reduce the burden on finance and HR teams, enabling them to focus on higher-value work for the organization and helping them respond more flexibly and with greater resilience to market or global economic changes.

With regard to the choice of modern technologies, businesses should decide which of these tools are most advantageous and necessary for the business, as well as adapted to its financial capabilities and the level and competence of its staff.

4. The use of advanced IT technologies in the finance profession

In order to diagnose what modern technologies are used in the work of the financier, a survey was used. The survey was conducted in the years 2022/23. The study was conducted in 2022 using the diagnostic survey method. In order to collect empirical material, the author's questionnaire was used. A survey was conducted among secondcycle students at universities in Małopolska, Lower and Upper Silesia. The survey covered 2000 respondents. Surveys were conducted anonymously and sent electronically. The study covered 3 Universities and 2000 students, of which about 21% were students of the University of Krakow, about 30% were students of the University of Katowice and about 50% of the people studied in Wrocław. The structure of students by type of university is shown in figure 1.

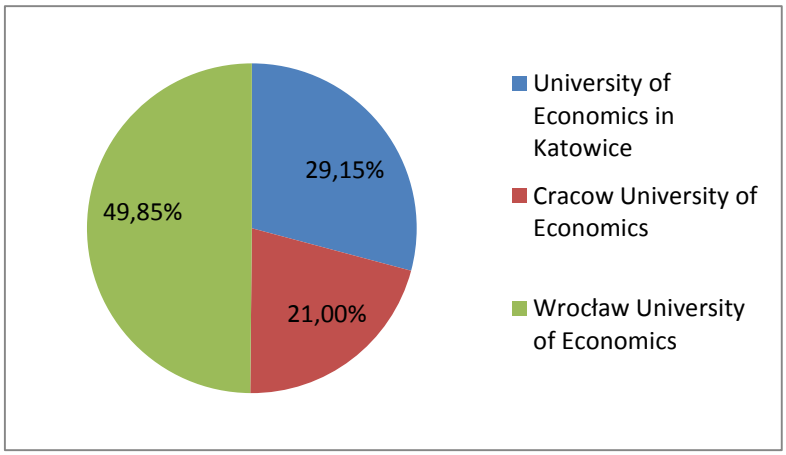

Figure 1. Structure of students participating in the survey by type of university.
Source: Own study.

To make the results of the study credible, it was investigated whether working students met at work with the use of advanced IT technologies regarding facilitation in the profession of accountants and financiers. Among those who noticed and drew attention to the use of AI solutions in the work of the financier, further research was carried out. Surveys of students who did not notice the introduction of modern technologies were rejected.

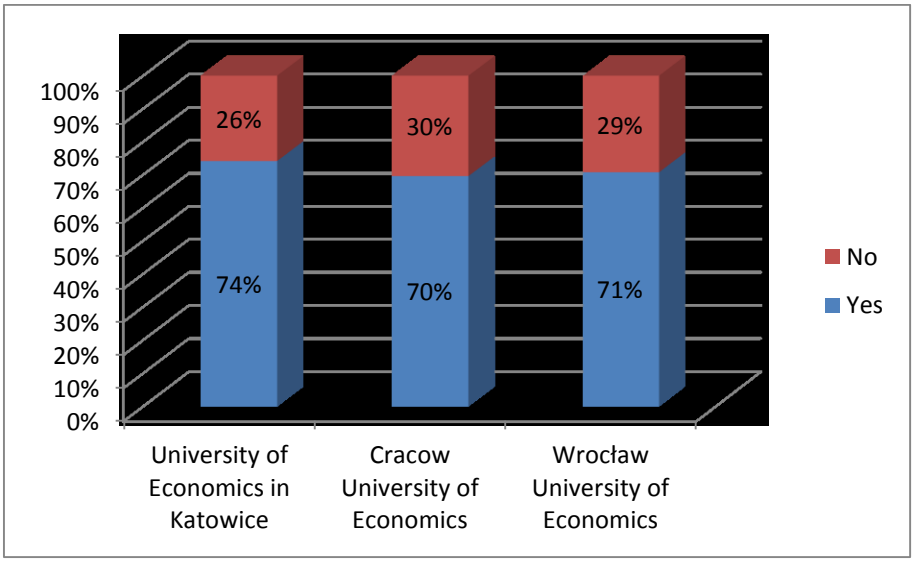

Figure 2. Share of respondents who do and do not use advanced information technology at work.
Source: Own study.

In each of the universities surveyed, more than 70% of respondents encountered the use of artificial intelligence in their professional work. Further questions in the survey related to detailing what elements of new technologies are present in respondents' workplaces and what problems are solved by advanced technologies in accounting work. The results are shown in figure 3. The largest number of respondents drew attention to BI systems, ERP, automatic payroll generation. A large number of respondents also noted the use of new technologies in conducting analyses and recording invoices.

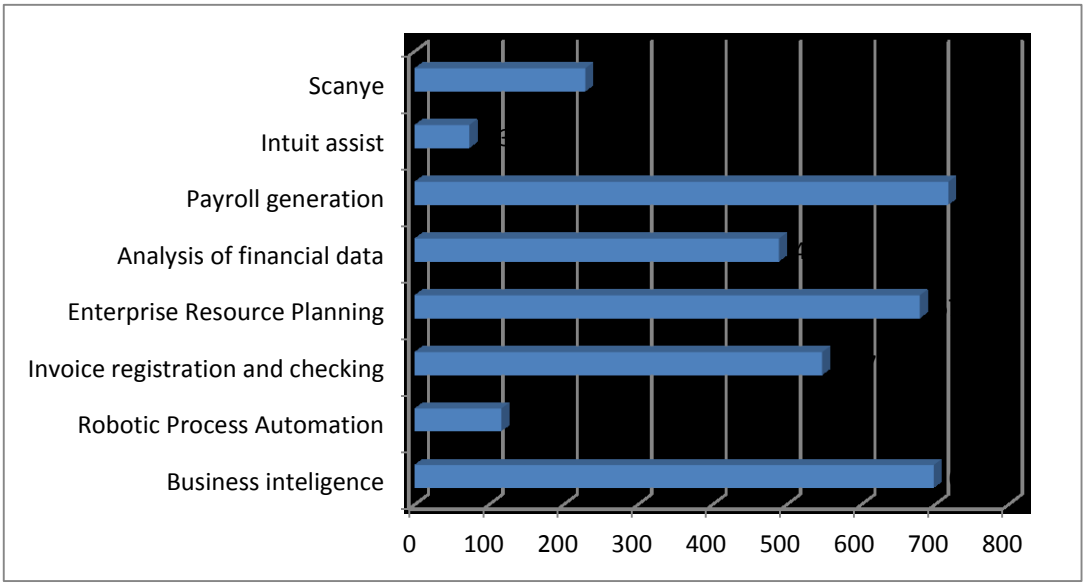

Figure 3. Elements of modern technology used in the work of financier and accountant.
Source: Own study.

Another question in the survey was about the benefits that come from using advanced technology. The responses are shown in figure 4.

Figure 4. Advantages of using modern technologies in the work of financier and accountant.
Source: Own study.

Among the biggest advantages of using modern technologies, respondents cited work reduction and increased efficiency, as well as the ability to conduct quick analyses for management decisions.

The last question asked about the risks of using advanced technologies in the work of a financier. The most frequently given answers are shown in figure 5.

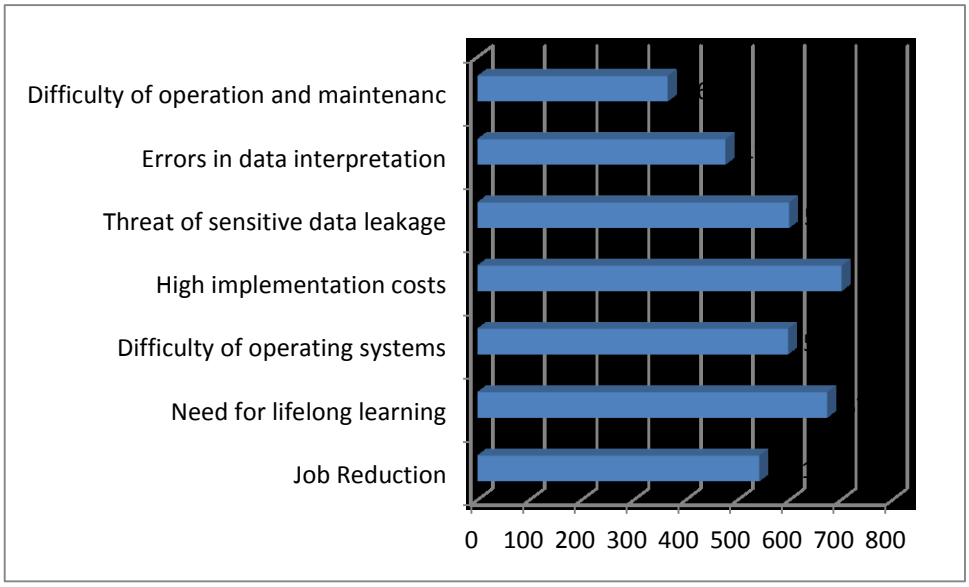

Figure 5. Threats of using advanced technologies in the work of a financier and accountant.
Source: Own study.

Among the biggest disadvantages in implementing modern technologies, respondents cited the high cost of implementing information systems and the need for continuing education and the threat of leaking sensitive data.

5. Conclusion

Concluding from the above analysis and survey data, it can be concluded that the majority of respondents recognize the benefits of using modern technology in the work of a financier. Key benefits such as improved productivity, reduced work time and increased ability to analyze large data sets and the ability to quickly generate the information necessary for management decisions were explicitly mentioned by the majority of respondents. This indicates that respondents have a positive attitude towards the potential opportunities presented by the use of modern technology in the work of a financier.

However, in addition to the benefits, respondents also have concerns and challenges related to the implementation of modern technologies. Of particular importance are concerns about the need to constantly adapt to changing technologies and the need for appropriate training and education. In addition, there are also concerns about data security and the risk of artificial intelligence systems misinterpreting data, and there are regulatory compliance issues. These issues require the development of appropriate risk management strategies, the implementation of effective security systems, and the provision of adequate training and education for employees to effectively use modern technologies.

The results of the survey are an important contribution to the discussion on the use of modern technologies in the work of a financier in the digital age, and provide a better understanding of the needs and expectations of practitioners in this field.

In summary, any growing finance division is currently facing many challenges in implementing modern technologies into daily processes. They have great potential to support the work of accountants and financiers, but their effective use requires consideration of a variety of aspects, including issues related to data security, regulatory compliance and the development of professional competence.

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References

1. Białas, M., Emerling, I. (2021). The Impact of the Covid Pandemic on the Value of Consumer and Mortgage Loans Granted by Polish Banks. In: K.S. Soliman (Eds.), *Innovation Management and Sustainable Economic Development in the Era of Global Pandemic.* Proceedings of the 38th International Business Information Management Association Conference (IBIMA), 23-24 November 2021. Seville, Spain: International Business Information Management Association.
2. Borowiec, L. (2022). Koszty i korzyści finansowe wdrożenia robotyzacji. *Zeszyty Teoretyczne Rachunkowości, No. 2*, pp. 11-26.
3. Conway, A. (2023). *New data from Microsoft shows how the pandemic is accelerating the digital transformation of cyber-security*. Retrieved from: https://www.microsoft.com/security/blog/2020/08/19/microsoft-shows-pandemic-accelerating-transformation-cyber-security/
4. Gossling, S., Scott, D., Hall, C.M. (2021). Pandemics, tourism and global change: a rapid assessment of COVID-19. *Journal of Sustainable Tourism*, *Vol. 29, No. 1*.
5. https://www.enova.pl/blog/nadazaj-w-biznesie/sztuczna-inteligencja-ai-w-ksiegowosci-czy-roboty-zastapia-ksiegowych/, 14.10.2024.
6. Iivari, N., Sharma, S., Ventä-Olkkonen, L. (2020). Digital transformation of everyday life–How COVID-19 pandemic transformed the basic education of the young generation and whyinformation management research should care? *International Journal of Information Management, 55, 102183.* Retrieved from: https://reader.elsevier.com/reader/sd/pii/S0268401220310264?token=3E3C097BB9068812B0F6D134FF9A4183CE862F60C355CE2F902FAD5ED1A3BA1C49EB2C280EDF3F8381B12C0AA94B9198), 23.10.2024.
7. Kokina, J., Blanchette, S. (2019). Early Evidence of Digital Labor in Accounting: Innovation with Robotic Process Automation. *International Journal of Accounting Information Systems, 35, 100431*, doi: 10.1016/j.accinf.2019.100431.
8. Koliński, A., Stajniak, M. (2018). (Eds.), *Efficiency of information flow in supply chains*. Radom: Corlog Publishing House.
9. Maier, B.F., Brockmann, D. (2020). Effective containment explains subexponential growth in recent confirmed COVID-19 cases in China. *Science, 368(6492).*
10. *Robot w służbie księgowości*. Raport firmy EY (2018).
11. Rzepecka, P. (2019). W jakim stopniu sztuczna inteligencja jest w stanie zastąpić człowieka? *Studia Pedagogiczne. Problemy społeczne, edukacyjne i artystyczne.* Kielce, doi: 10.25951/4080.
12. Sierpińska, M., Jachna, T. (2004). *Ocena przedsiębiorstwa według standardów światowych*. Warszawa: PWN.

13. Symański, P. (2023). *Rynek pracy po pandemii: Wyzwania i szanse dla poszukujących pracy*. Retrieved from: Infor.pl, 23.10.2024.
14. Talar, T. (2021). Cyfrowa transformacja a outsourcing usług księgowych. Moda czy konieczność? *HUMAN RIGHTS Evolution in the digital era*. Wyższa Szkoła Gospodarki Euroregionalnej im. Alcide De Gasperi w Józefowie.
15. World Economic Forum (2020). *A Visual History of Pandemics*. Retrieved from: https://www.weforum.org/agenda/2020/03/a-visual-history-of-pandemics, 30.06.2024.
16. World Economic Forum. *We need to rethink cybersecurity for a post-pandemic world. Here's how*. Retrieved from: https://www.weforum.org/agenda/2020/08/rethink-cybersecurity-post-pandemic-world/, 23.10.2024.

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ANALYSIS AND FORECASTING OF GROSS ELECTRICITY PRODUCTION – RENEWABLE ENERGY DIRECTIVE IN POLAND

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Purpose: This article aims to analyze data on gross electricity production in Poland under the Renewable Energy Directive and to forecast its future values.
Design/methodology/approach: The work determines forecasts for the coming years regarding the volume of gross energy production from renewable sources; the work uses models for forecasting time series, such as analytical models and the Holt model.
Findings: The work determined forecasts of gross energy production from renewable sources for the following years and determined the error values involved in these forecasts.
Practical implications: conducting data analysis and forecasting its future values using models in the study of historical data, the result of which may be an important element in the context of long-term planning, allows for understanding the dynamics of changes in the energy sector in Poland, as well as indicating directions of development.
Originality/value: The article analyzes gross energy production in Poland and presents projected values for the coming years, which are extremely important for the country's energy security, investments, and environmental protection.
Keywords: energy from renewable sources, forecasting.
Category of the paper: Research paper, general review.

1. Introduction

In the face of growing challenges related to global energy demand and the desire to reduce greenhouse gas emissions, renewable energy sources play a key role in transforming the energy sector. The Renewable Energy Directive introduced by the European Union sets ambitious goals for developing and promoting energy from renewable sources, including electricity. When analyzing the issue of supporting the production of energy from renewable sources in the European Union, it is necessary to define the treaty bases enabling the adoption of legal instruments regulating issues related to the promotion of the use of renewable energy due to two issues: provisions of the European Union's environmental policy (provisions of Title

XX of the Treaty (Art. 191-193 TFEU) on the Functioning of the European Union (TFEU) concerning the natural environment, which defines the objectives, principles and actions of the European Union in the field of environmental protection) and the provisions of the European Union's energy policy (provisions of Title XXI of the Treaty on the Functioning of the European Union (TFEU) relating to energy, which define the objectives and principles of the European Union's energy policy). Each of the mentioned policies assumes that different goals are achieved, and an extremely important aspect is the control of the legal boundaries of treaties (Pobrzeżyńska, 2020).

As one of the EU members, Poland has undertaken numerous actions to increase the share of renewable energy sources in the national energy mix. The production of electricity is the foundation of the modern economy, and it also has a significant impact on Poland's energy security, which is determined by several factors, such as the presence and development of hydrocarbon deposits, existing infrastructure enabling the import/export of energy raw materials, and the existence of production capabilities enabling access to energy carriers (e.g., fuels from refineries) or the existing raw material base (Surmacz, Paszkowski, 2023). Although the importance of renewable energy is increasing (solar energy, wind energy, water energy, geothermal energy (Słodczyk, 2010), biomass, and biogas), the share of renewable energy sources in Poland still needs to be higher. For Poland, in the coming years, the energy transformation process will be a big challenge; therefore, there is a need to implement plans to reduce greenhouse gas emissions.

The production of electricity from renewable energy sources, forecasting, and analysis are crucial in terms of energy security and ineffective investment planning. A precise analysis of gross electricity production in Poland, considering historical trends and forecasting methods, is an important tool for assessing the effectiveness of current activities and bandaging future investments in the energy sector. An extremely important aspect in the production of energy from renewable sources is state aid, as well as national support systems for the production of energy from renewable sources (Pobrzeżyńska, 2020), such as green certificate systems (Soliński, 2016), auction systems, prosumer (support system for RES micro-installations), blue system, white and red certificates, subsidies and support programs (My electricity, Clean air, Agroenergy).

This article aims to analyze data on gross electricity production in Poland under the Renewable Energy Directive and to forecast its future values using models in the analysis of historical data, the result of which may be an important element in the context of long-term planning. The forecasting methods used include various analytical approaches, including exponential, polynomial, power, linear models, and the Holt model. The analysis of the obtained results allows us not only to identify the best approach to forecasting but also to understand the dynamics of changes in the energy sector in Poland and to indicate the directions of development and potential challenges for further energy transformation in Poland.

2. Data analysis and forecasting based on analytical models and the Holt model

Table 1 presents data on Gross electricity production—Renewable Energy Directive for Poland from 2004 to 2023. The unit of gross electricity production is gigawatt-hour.

Table 1.
Gross electricity production - Renewable Energy Directive for Poland

Year	Gross electricity production
2004	2936.03
2005	3621.60
2006	4284.07
2007	5087.22
2008	6543.51
2009	8508.58
2010	10199.50
2011	12752.83
2012	16855.42
2013	17028.46
2014	19858.49
2015	21978.98
2016	22435.08
2017	22537.50
2018	22839.21
2019	24965.59
2020	27681.84
2021	30858.20
2022	37190.80
2023	43789.70

Source: https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ured_custom_14213015/default/table

The article aims to perform a forecast analysis regarding gross electricity production - Renewable Energy Directive in Poland based on data from 2004-2023. Table 2 below presents the data that will be analyzed. It also determines changes in gross electricity production from year to year. The most significant differences in the year-to-year increase in gross electricity production is gigawatt-hour can be observed in the final analyzed period - from 2019.

Table 2.
Gross electricity production - Renewable Energy Directive for Poland

Year	Gross electricity production	Absolute growth (absolute) for the immediately preceding period	Relative growth for the immediately preceding period
2004	2936.03	-	-
2005	3621.60	685.570	23.35%
2006	4284.07	662.477	18.29%
2007	5087.22	803.147	18.75%
2008	6543.51	1456.292	28.63%
2009	8508.58	1965.072	30.03%
2010	10199.50	1690.912	19.87%
2011	12752.83	2553.336	25.03%
2012	16855.42	4102.590	32.17%
2013	17028.46	173.041	1.03%

Cont. table 2.

2014	19858.49	2830.026	16.62%
2015	21978.98	2120.490	10.68%
2016	22435.08	456.104	2.08%
2017	22537.50	102.417	0.46%
2018	22839.21	301.712	1.34%
2019	24965.59	2126.378	9.31%
2020	27681.84	2716.251	10.88%
2021	30858.20	3176.359	11.47%
2022	37190.80	6332.600	20.52%
2023	43789.70	6598.900	17.74%

Source: own study based on https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ured_custom_14213015/default/table

Below, in Figure1, the time series regarding Gross electricity production for Poland is presented. This series is characterized by an increasing trend (the data show a clear upward trend, the values increase over subsequent years) with random fluctuations, without seasonal fluctuations (no repeatable seasonal patterns are visible in the data).

2.1. The linear model

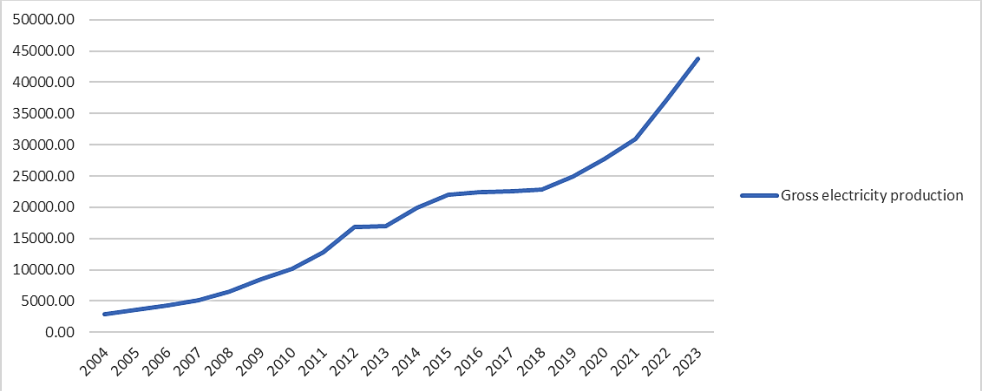

Figure 1. Gross electricity production values.

Source: own study based on https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ured__custom_14213015/default/table

An analytical method was proposed for forecasting, considering the comparison of errors obtained for various trend lines and the Holt model with the determination of forecasts divided into errors used to evaluate the model. In the next steps, the analyzed series of gross electricity production values and theoretical and forecast values are presented on the charts. Based on the determined parameters for individual trend lines, forecasts for the next 5 years and errors will be determined: MAE, MAPE, RMSE, and RMSPE. The next part of the work presents a prognostic analysis using the Holt model, specifying forecasts based on errors also specified in the analytical method.

The first analysis presents a linear model of the form $\hat{y} = a + b \cdot t$, with parameters a = -827.4 and b = 1897.6, respectively. On this basis, it can be concluded that in 2004-2023, gross electricity production values increased on average from year to year by 1897.6 gigawatt-hour. The coefficient of determination was determined to be 0.9487, which means that the linear model of the form y = -1827.4 + 1897.4·t explains 94.87% of the variability of gross electricity production. The standard error of the model estimate *s* was 2683.488, which means that the model predictions for gross electricity production, on average, differ from the actual values by about 2683.488 gigawatt-hour.

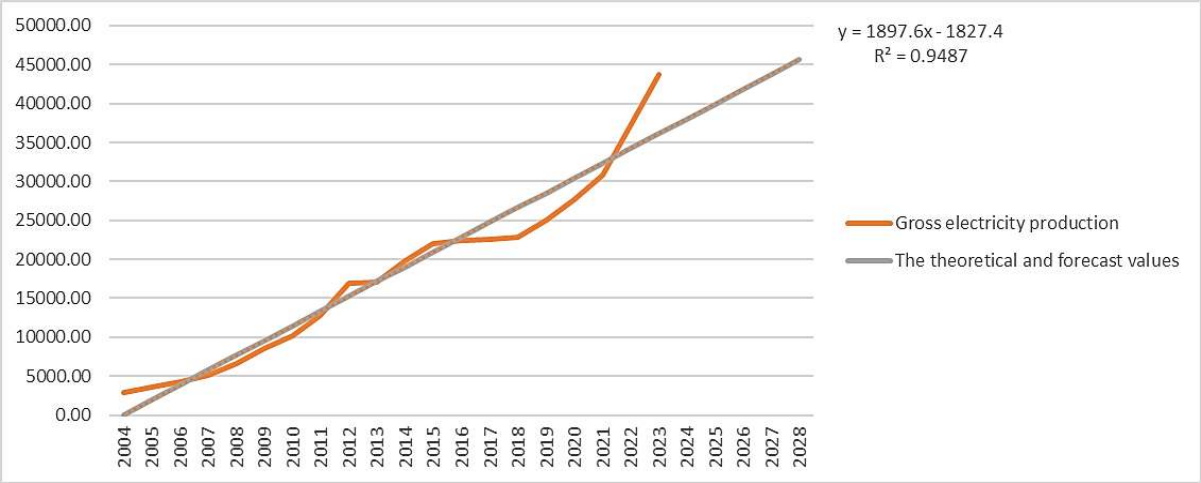

Figure 2. Gross electricity production values, along with theoretical and forecasted values for the linear model.

Source: own study based on https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ured__custom_14213015/default/table

Based on the linear model defined by the formula $\hat{y}_t = -1827.4 + 1897.4 \cdot t$, the **values** of expired forecasts were determined, as presented in Table 3.

Table 3.
Real values of gross electricity production yt and values resulting for the liner model $\hat{y}$

t	Year	y_t	$\hat{y}_t$	$(t - \bar{t})^2$
1	2004	2936.03	70.24	90.25
2	2005	3621.60	1967.86	72.25
3	2006	4284.07	3865.48	56.25
4	2007	5087.22	5763.10	42.25
5	2008	6543.51	7660.72	30.25
6	2009	8508.58	9558.34	20.25
7	2010	10199.50	11455.96	12.25
8	2011	12752.83	13353.58	6.25
9	2012	16855.42	15251.20	2.25
10	2013	17028.46	17148.82	0.25
11	2014	19858.49	19046.44	0.25
12	2015	21978.98	20944.06	2.25
13	2016	22435.08	22841.68	6.25
14	2017	22537.50	24739.30	12.25
15	2018	22839.21	26636.92	20.25
16	2019	24965.59	28534.54	30.25
17	2020	27681.84	30432.16	42.25

Cont. table 3.

18	2021	30858.20	32329.78	56.25
19	2022	37190.80	34227.40	72.25
20	2023	43789.70	36125.02	90.25
Sum			**665.00**	

Source: own study based on https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ured__custom_14213015/default/table

Based on the obtained trend line values for individual years, ex-ante errors (1) and relative ex-ante errors (2) will be determined for subsequent forecasts (Table 4). The patterns used are presented below (Zeliaś, Pawełek, Wanat, 2022):

- error *ante*:

$$v_t = s \cdot \sqrt{\frac{(T-\overline{t})^2}{\sum_{t=1}^{n}(t-\overline{t})^2} + \frac{1}{n} + 1} \tag{1}$$

- relative error *ex-ante*:

$$\eta_t = \frac{v_t}{y_t^*} \cdot 100\% \tag{2}$$

where:

s – standard error of model estimation,

T – the period for which the ex-ante error is determined,

$\overline{t}$ – average value from periods 1 to 20 or calculated from the formula (n+1)/2 = 10.5,

n − number of periods with actual values,

y_t^* – forecast determined for period t based on a trend line $\widehat{y_t}$.

The values presented in Table 4 indicate gross electricity production forecasts for the years 2024-2028, with a relative error ranging from 6.876% for 2028 to 7.782% in 2024. These forecasts can be considered acceptable at this stage of forecasting, but they should be compared with other errors such as MAE, MAPE, RMSE, and RMSPE, which will be implemented later in the work.

Table 4.
The forecasts, ex-ante and relative ex-ante error for the linear model

Year	Forecast	*The ex-ante error*	The relative ex-ante error
2024	38022.642	2958.890	7.782%
2025	39920.262	2998.877	7.512%
2026	41817.882	3041.900	7.274%
2027	43715.502	3087.831	7.063%
2028	45613.122	3136.543	6.876%

Source: own study based on https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ured__custom_14213015/default/table

Interval forecasts can also be determined based on the determined point forecasts. A pattern will be used for this purpose (3):

$$[y_t^* - u \cdot v_t \,; y_t^* + u \cdot v_t] \tag{3}$$

Due to differences in determining interval forecasts due to the adopted coefficient. If the hypothesis about the normal distribution of residuals was not verified or when this hypothesis was rejected, the coefficient *u* from Czebyszew's inequality (4) is used - used when the hypothesis about the normal distribution of residuals was not verified or when this hypothesis was rejected:

$$u = \sqrt{\frac{1}{1-p}} \tag{4}$$

where $p -$ credibility level (the probability that a random variable is within a specified range around the expected value).

An increase in the confidence level p causes u to increase, resulting in a broader range around the mean. For predictions, a larger u provides greater confidence that the value is within the range but at the cost of greater error tolerance.

When the distribution of residuals is normal, we can use Student's t-distribution tables to determine the coefficient u in order to estimate confidence intervals for the estimation. We read u for a given level of confidence *(1-α)* and *n-2* degrees of freedom (*2* - the number of parameters in a simple regression model (slope coefficient and intercept).

In order to determine interval forecasts, the Jarque-Bera test will be performed (5). This test is a statistical normality test that checks whether a sample of data comes from a normal distribution. The test is based on the analysis of two parameters: Skewness (a measure of the asymmetry of the data distribution) and kurtosis (a measure of the "pointiness" of the distribution compared to a normal distribution (Kukuła, Goryl, Jędrzejczyk, Osiewalski, Walkosz, 2009). The Jarque-Bera statistic is tested against a chi-square ($\chi 2$) distribution with 2 degrees of freedom.

- if JB > $\chi 2$ (number of degrees of freedom = 2,α) - we reject the H0 hypothesis (the distribution of residuals is not consistent with the normal distribution).
- if JB ≤ $\chi 2$ (number of degrees of freedom = 2,α) - there are no grounds to reject H0 (the distribution of residuals is consistent with the normal distribution).

The formula for the Jarque-Bera statistic:

$$JB = n \cdot \left(\frac{1}{6} \cdot B_1 + \frac{1}{24} \cdot (B_2 - 3)^2\right) \tag{5}$$

where:

$$B_1 = \left(\frac{1}{n} \cdot \frac{\sum_{t=1}^{n} e_t^3}{\bar{S}^3}\right)^2 \tag{6}$$

$$B_2 = \frac{1}{n} \cdot \frac{\sum_{t=1}^{n} e_t^4}{\bar{S}^4} \tag{7}$$

$$\bar{S} = \sqrt{\frac{1}{n} \cdot \sum_{t=1}^{n} e_t^2} \tag{8}$$

$$e_t = y_t - \hat{y_t} \tag{9}$$

Below, in Table 5, calculations for the subsequent factors of the JB statistics are presented:

Table 5.
The partial factors for the Jarque-Bera test

t	Year	y_t	$\hat{y}_t$	$(y_t - \hat{y}_t)^2$	$(y_t - \hat{y}_t)^3$	$(y_t - \hat{y}_t)^4$
1	2004	2936.03	70.24	8212730.053	23535927745.785	67448934920702.800
2	2005	3621.60	1967.86	2734842.783	4522707984.429	7479365045343.470
3	2006	4284.07	3865.48	175220.0166	73345855.002	30702054203.241
4	2007	5087.22	5763.10	456814.0529	-308751576.173	208679078911.332
5	2008	6543.51	7660.72	1248154.414	-1394448487.123	1557889441559.910
6	2009	8508.58	9558.34	1101988.54	-1156819544.537	1214378743137.820
7	2010	10199.50	11455.96	1578703.106	-1983584450.135	2492303496546.640
8	2011	12752.83	13353.58	360898.9202	-216809532.962	130248030565.972
9	2012	16855.42	15251.20	2573525.852	4128504884.553	6623035308433.790
10	2013	17028.46	17148.82	14486.01124	-1743505.119	209844521.708
11	2014	19858.49	19046.44	659422.03	535482371.369	434837413667.445
12	2015	21978.98	20944.06	1071055.142	1108454181.254	1147159117681.450
13	2016	22435.08	22841.68	165322.0693	-67219650.345	27331386611.026
14	2017	22537.50	24739.30	4847928.849	-10674175914.013	23502414123002.200
15	2018	22839.21	26636.92	14422596.54	-54772830164.216	208011290908501.000
16	2019	24965.59	28534.54	12737414.72	-45459215201.533	162241733701275.000
17	2020	27681.84	30432.16	7564263.37	-20804149324.006	57218080326151.800
18	2021	30858.20	32329.78	2165552.702	-3186787728.259	4689618505086.570
19	2022	37190.80	34227.40	8781728.847	26023759392.655	77118761545760.500
20	2023	43789.70	36125.02	58747290.16	450279067466.276	3451244100864630.000
Sum				129619938.17	370180714802.902	4072821073856300.000

Source: own study based on https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ured__custom_14213015/default/table

Based on the above data presented in Table 5, individual factors of the JB statistics were determined and presented in Table 6.

Table 6.
The partial factors for the Jarque-Bera test

e_t^2	129619938.17
e_t^3	370180714802.902
e_t^4	4072821073856300.000
$\bar{S}$	2545.780
B_1	1.258
B_2	4.848

Source: own study based on https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ured__custom_14213015/default/table

The value of the JB statistic was 7.041. Comparing it with the critical value $\chi 2 = 5.991$, hypothesis H0 regarding the normality of the distribution of residuals should be rejected. Due to the inconsistency of the distribution of residuals with the normal distribution, we adopt the coefficient *u* of Czebyszew's inequality (4) to determine interval forecasts:

$$u = \sqrt{\frac{1}{1-p}} = \sqrt{\frac{1}{1-0.95}} = 4.472 \tag{10}$$

Assuming p = 0.95 means that at least 95% of the values will be in the range $\mu \pm 4.47\sigma$, where σ is the standard deviation.

Table 7.
The interval forecasts

Year	t	The point forecast	The interval forecast	
			from	to
2024	21	38022.642	24790.083	51255.201
2025	22	39920.262	26508.877	53331.648
2026	23	41817.882	28214.094	55421.670
2027	24	43715.502	29906.303	57524.702
2028	25	45613.122	31586.074	59640.171

Source: own study based on https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ured__custom_14213015/default/table

With a probability of 95%, the value of gross electricity production will be in the range:

a) in 2024, from 24790.083 to 51255.201 gigawatt-hour,
b) in 2025, from 26508.877 to 53331.648 gigawatt-hour,
c) in 2026, from 28214.094 to 55421.670 gigawatt-hour,
d) in 2027, from 29906.303 to 57524.702 gigawatt-hour,
e) in 2028, from 31586.074 to 59640.171 gigawatt-hour.

In the further part of the analysis, the error values described by the formulas were determined (11) – (14) (Zeliaś, Pawełek, Wanat, 2022).

a) Mean Absolute Error

$$\boldsymbol{MAE = \frac{1}{n} \cdot \sum_{i=1}^{n} |y_t - \hat{y}_t|} \tag{11}$$

b) Mean Absolute Percentage Error

$$\boldsymbol{MAPE = \frac{1}{n} \cdot \sum_{i=1}^{n} \left|\frac{y_t - \hat{y}_t}{y_t}\right| \cdot 100\%} \tag{12}$$

c) Root Mean Squared Error

$$\boldsymbol{RMSE = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} (y_t - \hat{y}_t)^2}} \tag{13}$$

d) Root mean Squared Percentage Error

$$\boldsymbol{RMSPE = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} \left(\frac{y_t - \hat{y}_t}{y_t}\right)^2} \cdot 100\%} \tag{14}$$

Table 8 below shows the values of the proposed errors and their components.

Table 8.
MAE, MAPE, RMSE, and RMSPE error values for the linear model

t	Year	y_t	$\hat{y}_t$	MAE	MAPE	RMSE	RMSPE
1	2004	2936.03	70.24	2865.79	0.98	8212730.05	0.95273
2	2005	3621.60	1967.86	1653.74	0.46	2734842.78	0.20851
3	2006	4284.07	3865.48	418.59	0.10	175220.02	0.00955
4	2007	5087.22	5763.10	675.88	0.13	456814.05	0.01765
5	2008	6543.51	7660.72	1117.21	0.17	1248154.41	0.02915
6	2009	8508.58	9558.34	1049.76	0.12	1101988.54	0.01522
7	2010	10199.50	11455.96	1256.46	0.12	1578703.11	0.01518
8	2011	12752.83	13353.58	600.75	0.05	360898.92	0.00222
9	2012	16855.42	15251.20	1604.22	0.10	2573525.85	0.00906
10	2013	17028.46	17148.82	120.36	0.01	14486.01	0.00005
11	2014	19858.49	19046.44	812.05	0.04	659422.03	0.00167

Cont. table 8.

12	2015	21978.98	20944.06	1034.92	0.05	1071055.14	0.00222
13	2016	22435.08	22841.68	406.60	0.02	165322.07	0.00033
14	2017	22537.50	24739.30	2201.80	0.10	4847928.85	0.00954
15	2018	22839.21	26636.92	3797.71	0.17	14422596.54	0.02765
16	2019	24965.59	28534.54	3568.95	0.14	12737414.72	0.02044
17	2020	27681.84	30432.16	2750.32	0.10	7564263.37	0.00987
18	2021	30858.20	32329.78	1471.58	0.05	2165552.70	0.00227
19	2022	37190.80	34227.40	2963.40	0.08	8781728.85	0.00635
20	2023	43789.70	36125.02	7664.68	0.18	58747290.16	0.03064
Sum				38034.76	3.14	129619938.17	1.37
Error				**1901.74**	**15.72%**	**2545.78**	**26.18%**

Source: own study based on https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ured__custom_14213015/default/table

Based on the calculations in the table above, the estimated errors were: MAE = 1901.74 (the linear model forecasts on average differ from the actual data by 1901.74 gigawatt-hour), MAPE = 15.72% (the model forecasts on average differ from the actual data by 15.72% of their value.). RMSE = 2545.78 - this error penalizes more significant errors more severely than MAE, which indicates that there are errors in the data that are significantly different. It is more sensitive to large differences between the actual and predicted values, resulting in more significant errors being "penalized" than smaller ones. The RMSPE error measure equals 26.18% - RMSPE emphasizes significant percentage errors more, especially at large actual values). In summary, a higher RMSE than MAE indicates more significant errors in the data. The percentage error of RMSPE (26.18%) is larger than MAPE (15.72%), which indicates a possible misfit of the model in the final, larger values of the series. A linear trend is not ideal for this data because higher values result in more significant errors, as seen in the RMSPE. It is worth considering more flexible models, such as polynomial, exponential, or power-law trends.

2.2. The polynomial model

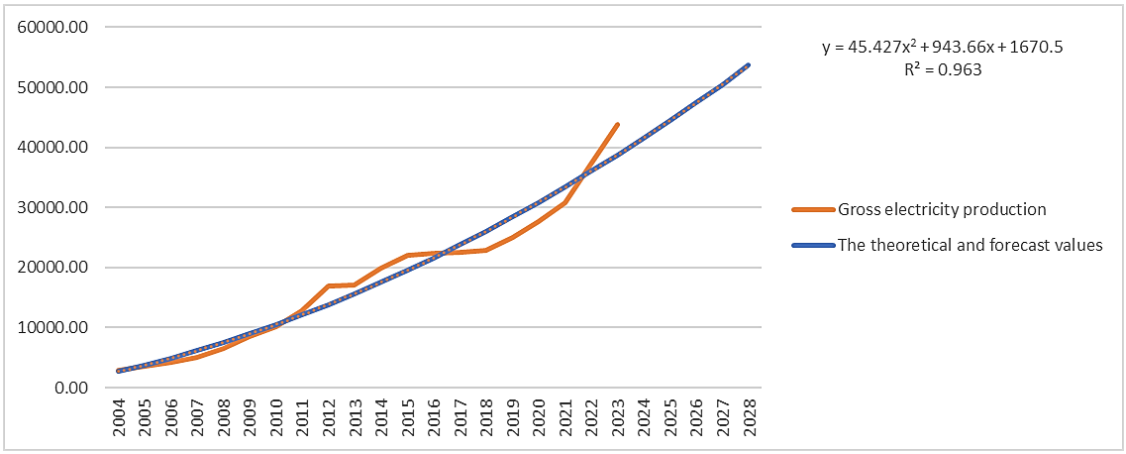

Figure 3. Gross electricity production values, along with theoretical and forecasted values for the polynomial model.

Source: own study based on https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ured__custom_14213015/default/table

Based on the polynomial model defined by the formula $\widehat{y_t} = 45.527 \cdot t^2 + 943.66 \cdot t + 1670.5$, forecasts for the following years 2024-2028 were calculated, respectively: 41520.49 gigawatt-hour (2024), 44417.49 gigawatt-hour (2025), 47405.35 gigawatt-hour (2026), 50484.06 gigawatt-hour (2027), 53653.62 gigawatt-hour (2028). The standard error of the model was 2343.85. In Table 9, the values of the proposed errors and their components are presented below.

Table 9.
MAE, MAPE, RMSE, and RMSPE error values for the polynomial model

t	Year	y_t	$\widehat{y_t}$	MAE	MAPE	RMSE	RMSPE
1	2004	2936.03	2 659.55	276.47	0.09	76437.15	0.00887
2	2005	3621.60	3 739.50	117.90	0.03	13900.29	0.00106
3	2006	4284.07	4 910.29	626.22	0.15	392148.70	0.02137
4	2007	5087.22	6 171.94	1084.72	0.21	1176615.67	0.04546
5	2008	6543.51	7 524.44	980.93	0.15	962221.03	0.02247
6	2009	8508.58	8 967.80	459.21	0.05	210874.98	0.00291
7	2010	10199.50	10 502.00	302.51	0.03	91510.46	0.00088
8	2011	12752.83	12 127.06	625.77	0.05	391585.90	0.00241
9	2012	16855.42	13 842.98	3012.44	0.18	9074820.94	0.03194
10	2013	17028.46	15 649.74	1378.72	0.08	1900864.26	0.00656
11	2014	19858.49	17 547.36	2311.12	0.12	5341295.23	0.01354
12	2015	21978.98	19 535.84	2443.14	0.11	5968938.07	0.01236
13	2016	22435.08	21 615.16	819.92	0.04	672266.70	0.00134
14	2017	22537.50	23 785.34	1247.84	0.06	1557113.90	0.00307
15	2018	22839.21	26 046.38	3207.16	0.14	10285902.31	0.01972
16	2019	24965.59	28 398.26	3432.67	0.14	11783235.92	0.01891
17	2020	27681.84	30 841.00	3159.16	0.11	9980289.09	0.01302
18	2021	30858.20	33 374.59	2516.39	0.08	6332230.60	0.00665
19	2022	37190.80	35 999.04	1191.76	0.03	1420298.33	0.00103
20	2023	43789.70	38 714.34	5075.36	0.12	25759326.53	0.01343
Sum				34269.43	1.97	93391876.05	0.25
Error				1 713.47	9.85%	2160.92	11.11%

Source: own study based on
https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ured__custom_14213015/default/table

Based on the calculations in the table above, the polynomial model predictions were estimated to differ from the actual data on average by 1713.47 gigawatt-hour (MAE). The MAPE error value was 9.85%, which means that the model's predictions, on average, differ from the actual data by 9.85% of their value. The RMSE error was set at 2160.92 - this value is greater than the MAE value, which indicates that errors in the data significantly differ (large differences between the actual and forecast values). The RMSPE error measure is 11.11%. The share of the MAE error in the forecasts was, respectively, 4.13%, 3.86%, 3.61%, 3.39%, and 3.19%, while the share of the RMSE error in the forecasts was estimated at the following levels: 5.20%, 4.87%, 4.56%, 4.28%, respectively and 4.03%.

2.3. The power model

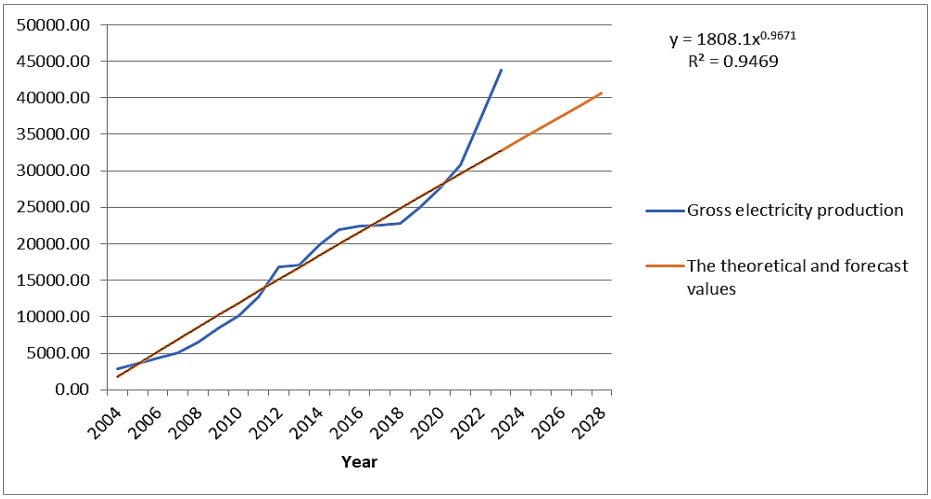

Figure 4. Gross electricity production values, along with theoretical and forecasted values for the power model.

Source: own study based on https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ured__custom_14213015/default/table

Based on the power model defined by the formula $\hat{y}_t = 1808.1 \cdot t^{0.9671}$, the following forecasts were calculated for the following years 2024-2028: 34352.97 gigawatt-hour (2024), 35933.83 gigawatt-hour (2025), 37512.32 gigawatt-hour (2026), 39088.56 gigawatt-hour (2027), 40662.65 gigawatt-hour (2028). The standard error of the power model was 3261.1.

Table 10.
MAE, MAPE, RMSE, and RMSPE error values for the power model

t	Year	y_t	ln(t)	$\hat{y}_t$	MAE	MAPE	RMSE	RMSPE
1	2004	2936.03	0	1808.07	1127.96	0.38	1272292.64	0.14759
2	2005	3621.60	0.693147181	3534.66	86.94	0.02	7557.78	0.00058
3	2006	4284.07	1.098612289	5231.78	947.71	0.22	898155.59	0.04894
4	2007	5087.22	1.386294361	6910.05	1822.83	0.36	3322699.52	0.12839
5	2008	6543.51	1.609437912	8574.43	2030.91	0.31	4124608.35	0.09633
6	2009	8508.58	1.791759469	10227.82	1719.24	0.20	2955773.77	0.04083
7	2010	10199.50	1.945910149	11872.14	1672.64	0.16	2797731.16	0.02689
8	2011	12752.83	2.079441542	13508.72	755.89	0.06	571373.00	0.00351
9	2012	16855.42	2.197224577	15138.58	1716.84	0.10	2947543.73	0.01037
10	2013	17028.46	2.302585093	16762.48	265.98	0.02	70745.84	0.00024
11	2014	19858.49	2.397895273	18381.04	1477.44	0.07	2182842.66	0.00554
12	2015	21978.98	2.48490665	19994.77	1984.21	0.09	3937086.85	0.00815
13	2016	22435.08	2.564949357	21604.07	831.01	0.04	690574.87	0.00137
14	2017	22537.50	2.63905733	23209.31	671.81	0.03	451329.93	0.00089
15	2018	22839.21	2.708050201	24810.78	1971.57	0.09	3887075.71	0.00745
16	2019	24965.59	2.772588722	26408.74	1443.15	0.06	2082675.86	0.00334
17	2020	27681.84	2.833213344	28003.41	321.57	0.01	103409.69	0.00013
18	2021	30858.20	2.890371758	29595.01	1263.19	0.04	1595651.78	0.00168
19	2022	37190.80	2.944438979	31183.70	6007.10	0.16	36085284.32	0.02609
20	2023	43789.70	2.995732274	32769.64	11020.06	0.25	121441774.96	0.06333
Sum					39138.06	2.68	191426187.98	0.62
Error					1 956.90	13.41%	3093.75	17.63%

Source: own study based on https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ured__custom_14213015/default/table

Based on the calculations in Table 10, an MAE error of 1956.9 was calculated, which means that the power model forecasts, on average, differ from the actual data by 1956.9 gigawatt-hour. The MAPE error value was 13.41%, which means that the model's predictions, on average, differ from the actual data by 13.41% of their value. The RMSE error value was 3093.75. The RMSPE error measure is 17.63. The share of the MAE error in the forecasts was 5.7%, 5.45%, 5.22%, 5.01%, and 4.81%, respectively, while the share of the RMSE error in the forecasts was estimated at the following levels: 9.01%, 8.61%, 8.25%, 7.91%, 7.61%.

2.4. The exponential model

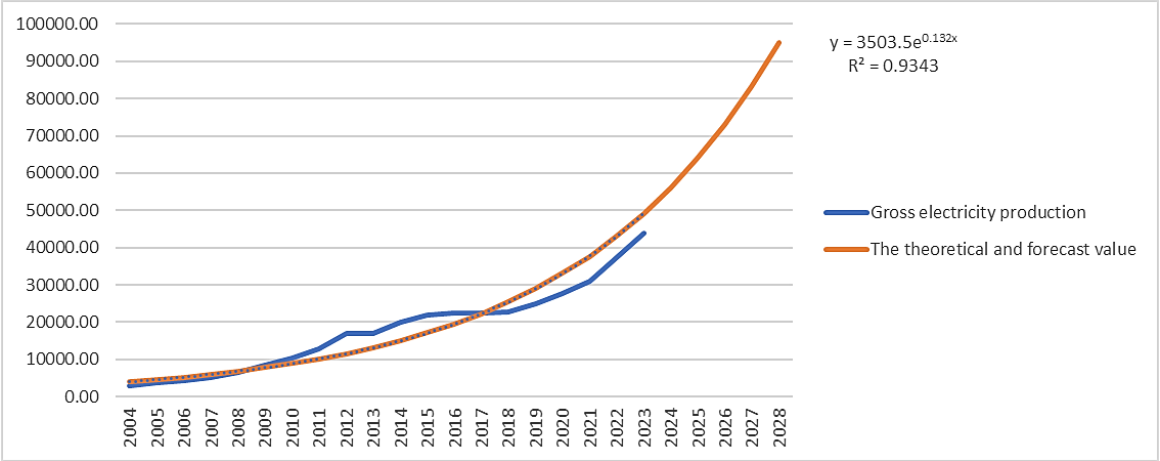

Figure 5. Gross electricity production values, along with theoretical and forecasted values for the exponential model.

Source: own study based on https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ured__custom_14213015/default/table

Based on the power model defined by the formula $\hat{y}_t = 3503.5 \cdot e^{0132}$, the forecasts for the following years 2024-2028 were calculated, respectively: 55987.76 gigawatt-hour (2024), 63886.19 gigawatt-hour (2025), 72898.88 gigawatt-hour (2026), 83183.029 gigawatt-hour (2027), 94918.005 gigawatt-hour (2028). The standard error of the power model was 3896.2776. Table 11 below shows the error values and their components.

Table 11.
MAE, MAPE, RMSE, and RMSPE error values for the exponential model

t	Year	y_t	ln(y)	$\hat{y}_t$	MAE	MAPE	RMSE	RMSPE
1	2004	2936.03	7.9848	3 997.75	1061.72	0.36	1127258.46	0.13077
2	2005	3621.60	8.1947	4561.72957	940.13	0.26	883851.13	0.06739
3	2006	4284.07	8.3627	5205.271759	921.20	0.22	848607.15	0.04624
4	2007	5087.22	8.5345	5939.601124	852.38	0.17	726553.58	0.02807
5	2008	6543.51	8.7862	6777.52539	234.01	0.04	54762.27	0.00128
6	2009	8508.58	9.0488	7733.659123	774.92	0.09	600508.56	0.00829
7	2010	10199.50	9.2301	8824.678623	1374.82	0.13	1890122.82	0.01817
8	2011	12752.83	9.4535	10069.61279	2683.22	0.21	7199665.34	0.04427
9	2012	16855.42	9.7324	11490.175	5365.25	0.32	28785875.36	0.10132
10	2013	17028.46	9.7426	13111.14184	3917.32	0.23	15345405.07	0.05292
11	2014	19858.49	9.8964	14960.78522	4897.70	0.25	23987502.29	0.06083
12	2015	21978.98	9.9978	17071.3655	4907.61	0.22	24084670.26	0.04986

Cont. table 11.

13	2016	22435.08	10.0184	19479.69413	2955.39	0.13	8734323.39	0.01735
14	2017	22537.50	10.0229	22227.7757	309.72	0.01	95929.14	0.00019
15	2018	22839.21	10.0362	25363.54059	2524.33	0.11	6372234.85	0.01222
16	2019	24965.59	10.1253	28941.68089	3976.09	0.16	15809298.80	0.02536
17	2020	27681.84	10.2285	33024.60435	5342.76	0.19	28545120.21	0.03725
18	2021	30858.20	10.3372	37683.52282	6825.32	0.22	46585031.61	0.04892
19	2022	37190.80	10.5238	42999.69432	5808.89	0.16	33743253.26	0.02440
20	2023	43789.70	10.6872	49065.84028	5276.14	0.12	27837656.25	0.01452
				Sum	60948.95	3.60	273257629.80	0.79
				Error	3 047.45	18.00%	3696.33	19.87%

Source: own study based on https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ured__custom_14213015/default/table

Based on the calculations in the table above, the exponential model predictions were estimated to differ from the actual data by, on average, 3047.45 gigawatt-hours (MAE). The MAPE error value was 18%, which means that the model's predictions, on average, differ from the actual data by 18% of their value. The RMSE error is 3696.33, while the RMSPE error is 19.87%. The share of the MAE error in the forecasts was 5.44%, 4.77%, 4.18%, 3.66%, and 3.21%, respectively, while the share of the RMSE error in the forecasts was estimated at 6.6%, 5.79%, 5.07%, 4.44%, 3.89%, respectively.

Based on the analysis of forecast estimation using the analytical method, the most reliable seems to be the polynomial model for which the smallest errors were estimated: MAE 1713.47, MAPE 9.85%, RMSE 2160.92, and RMSPE 11.11%. For this model, the smallest standard error of the model wat the level of 2343.85.

2.5. Holt's model

The paper presents a prognostic analysis based on an analytical model. The following section presents the use of the Holt model to estimate forecasts for the following years, including the determination of errors (Zeliaś, Pawełek, Wanat, 2022). An Excel spreadsheet and the Solver add-in were used to find the optimal solution. Below are the formulas used in Holt's model:

a) *F* equation

$$F_t = \alpha \cdot y_t + (1 - \alpha) \cdot (F_{t-1} + S_{t-1}) \tag{15}$$

for t = 1:

$$F_t = y_1 \tag{16}$$

b) *S* equation

$$S_t = \beta \cdot (F_t - F_{t-1}) + (1 - \beta) \cdot S_{t-1} \tag{17}$$

for t = 1:

$$S_1 = y_2 - y_1 \tag{18}$$

c) Forecast for t > n:

$$y_t^* = F_n + (t - n) \cdot S_n \tag{19}$$

for 2 <= t < = n

$$y_t^* = F_{t-1} + S_{t-1} \tag{20}$$

Table 12 below shows the values of the *F* and *S* equations, expired forecasts, and individual error factor values for the initial value of the alpha and beta parameters equal to 0 (before running the solver).

Table 12.
Data values, F and S equations, expired forecasts and error factors for the Holt model

t	y_t	F_t	S_t	y_t*	MAE	MAPE	RMSE	RMSPE
1	2936.03	2936	686	-				
2	3621.60	3622	686	3622				
3	4284.07	4307	686	4307	23.09	0.01	533.29	0.00003
4	5087.22	4993	686	4993	94.48	0.02	8927.23	0.00034
5	6543.51	5678	686	5678	865.21	0.13	748581.42	0.01748
6	8508.58	6364	686	6364	2144.71	0.25	4599772.41	0.06354
7	10199.50	7049	686	7049	3150.05	0.31	9922815.00	0.09538
8	12752.83	7735	686	7735	5017.82	0.39	25178477.41	0.15482
9	16855.42	8421	686	8421	8434.84	0.50	71146458.35	0.25042
10	17028.46	9106	686	9106	7922.31	0.47	62762948.20	0.21645
11	19858.49	9792	686	9792	10066.76	0.51	101339717.30	0.25697
12	21978.98	10477	686	10477	11501.68	0.52	132288711.83	0.27385
13	22435.08	11163	686	11163	11272.22	0.50	127062876.10	0.25244
14	22537.50	11848	686	11848	10689.06	0.47	114256089.20	0.22494
15	22839.21	12534	686	12534	10305.21	0.45	106197270.70	0.20359
16	24965.59	13220	686	13220	11746.01	0.47	137968844.89	0.22136
17	27681.84	13905	686	13905	13776.70	0.50	189797325.12	0.24769
18	30858.20	14591	686	14591	16267.48	0.53	264631035.69	0.27791
19	37190.80	15276	686	15276	21914.51	0.59	480245923.86	0.34721
20	43789.70	15962	686	15962	27827.84	0.64	774388901.69	0.40385
Sum					173019.98	7.25	2602545209.67	3.51

Source: own study based on https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ured__custom_14213015/default/table

Based on the analyses performed, the alpha and beta parameters' values and the forecasts that were obtained were determined for various errors. The results are presented in the table below: Table 13.

Table 13.
MAE, MAPE, RMSE, and RMSPE error values, alpha and beta parameters, and forecasts for the following years

	MAE	MAPE	RMSE	RMSPE
Error	1098.342	5.85%	1484.469	7.50%
alfa	0.905	0.925	0.825	0.747
beta	0.980	0.829	0.980	0.980
Forecast t = 21	50506.269	50256.513	50455.892	50299.248
Forecast t = 22	57307.055	56815.602	57352.659	57239.112
Forecast t = 23	64107.842	63374.691	64249.426	64178.975
Forecast t = 24	70908.628	69933.781	71146.193	71118.838
Forecast t = 25	77709.415	76492.870	78042.960	78058.701

Source: own study based on https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ured__custom_14213015/default/table

Based on the obtained results, comparing the MAE error and RMSE, a smaller value was obtained for the MAE error with forecasts for the following years: 50506.269, 57307.055, 64107.842, 70908.628, 77709.415, respectively. Looking at the MAPE and RMSPE percentage errors, a smaller value was determined for the MAPE error, for which the forecasts were set at the following levels: 50256.513, 56815.602, 63374.691, 69933.781, 76492.87. The share of the MAE error in the forecasts was, respectively, for the following years: 2.17%, 1.92%, 1.71%, 1.55%, 1.41%, while the share of the RMSE error in the forecasts was estimated at the following levels: 2.94%, 2.59%, 2.31%, 2.09%, 1.9%.

3. Summary

This article presents a detailed analysis and forecasting of gross electricity production in Poland in the context of implementing the assumptions of the Renewable Energy Directive. Various forecasting methods were used, such as linear, polynomial, power-law, exponential, and Holt models, to accurately assess the dynamics of changes in the renewable energy sector. The analysis results indicate significant differences in the effectiveness of individual forecasting methods. Comparison of forecast errors such as MAE, RMSE, MAPE, and RMSPE made it possible to assess the accuracy of each model and indicate the best approach depending on the time perspective.

The methods used provide valuable conclusions for planning the development of the renewable energy sector in Poland. Forecasts indicate a further increase in renewable energy production, which confirms progress in achieving EU goals. At the same time, the results emphasize the need to invest in energy infrastructure, further develop renewable energy, and integrate the power system.

The analyses can serve as the basis for making strategic decisions in the energy sector, supporting the transformation towards sustainable development and climate neutrality.

References

1. Acedański, J., Hadaś-Dyduch, M., Szkutnik, W. (2016). *Prognozowanie zjawisk ekonomicznych i finansowych. Część 1. Prognozowanie z Excelem*. Katowice: Wydawnictwo Uniwersytet Ekonomiczny w Katowicach.
2. Brodziński, Z., Kramarz, M., Sławomirski, M.R. (Eds.) (2016). *Energia odnawialna wizytówką nowoczesnej gospodarki.* Toruń: Adam Marszałek.

3. Bukowski, M. (2012). *Efektywność ekonomiczna produkcji energii w małych elektrowniach wodnych.* Raszyn: ITP.
4. Dubel, A. (2016). Klasyfikacje kosztów zapobiegania zmianom klimatu i adaptacja do nich oraz ich znaczenie dla podejmujących strategiczne decyzje. In: T. Walczykiewicz (Ed.), *Problemy planowania w gospodarce wodnej i oceny stanu hydromorfologicznego rzek*. Warszawa: IMGW-PIB.
5. https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ured__custom_14213015/default/table
6. Jabłoński, W., Wnuk, J. (2004). *Odnawialne źródła energii w polityce energetycznej Unii Europejskiej i Polski. Efektywne zarządzanie inwestycjami – studia przypadków*. Sosnowiec: Wydawnictwo Wyższej Szkoły Zarządzania i Marketingu w Sosnowcu.
7. Kukuła, K., Goryl, A., Jędrzejczyk, Z., Osiewalski, J., Walkosz, A. (2009). *Wprowadzenie do ekonometrii*. Warszawa: PWN.
8. Kundzewicz, Z., Hov, O., Okruszko, T. (Eds.) (2017). *Zmiany klimatu i ich wpływ na wybrane sektory w Polsce*. Poznań: Instytut Środowiska Rolniczego i Leśnego Polskiej Akademii Nauk.
9. Kurałowicz, Z. (Eds.) (2012). *Techniczne aspekty ochrony środowiska. Woda źródłem energii.* Gdańsk: Wydawnictwo Politechniki Gdańskiej.
10. Nazarko, J. (Ed.) (2018). *Prognozowanie w zarzadzaniu przedsiębiorstwem. Cz. IV. Prognozowanie na podstawie modeli trendu*. Białystok: Oficyna Wydawnicza Politechniki Bialostockiej.
11. Pietkun-Greber, I., Ratuszny, P. (Eds.) (2017). *Odnawialne źródła energii. Teoria i praktyka. Tom II*. Brzesko: COTI Conference Time Stanisław Kurtyka.
12. Pobrzeżyńska, M. (2020). *Pomoc państwa na produkcję energii ze źródeł odnawialnych w prawie Unii Europejskiej.* Warszawa: C.H. Beck.
13. Słodczyk, E. (2017). Funkcjonowanie elektrowni geotermalnych oraz ich wpływ na środowisko przyrodnicze na przykładzie elektrowni działających na Islandii. In: I. Pietkun-Greber, P. Ratuszny (Eds.), *Odnawialne źródła energii. Teoria i praktyka. Tom II*. Brzesko: COTI Conference Time Stanisław Kurtyka.
14. Soliński, B. (2016). Zielone certyfikaty jako system wsparcia odnawialnych źródeł energii w Polsce – istota i efekty działania. In: Z. Brodziński, M. Kramarz, M.R. Sławomirski (Eds.), *Energia odnawialna wizytówką nowoczesnej gospodarki.* Toruń: Adam Marszałek.
15. Surmacz, B., Paszkowski, M. (Eds.) (2023). *Raport. Bezpieczeństwo energetyczne państwa Europy Środkowej i Wschodniej*. Lublin: Instytut Europy Środkowej.
16. Wiśniewski, J.W. (2020). *Prognozowanie z wielorównaniowych mikromodeli ekonometrycznych.* Toruń: Wydawnictwo Naukowe Uniwersytetu Mikołaja Kopernika.
17. Zeliaś, A., Pawełek, B., Wanat, S. (2022). *Prognozowanie ekonomiczne. Teoria, przykłady, zadania.* Warszawa: PWN.

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ANALYSIS OF THE SHARE OF ENERGY FROM RENEWABLE SOURCES IN THE ELECTRICITY SECTOR IN POLAND AND THE EUROPEAN UNION

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Purpose: The article aims to analyze the share and forecast the share in the following year's share of renewable energy sources in Poland and the European Union; it will present the situation of Poland and the European Union to determine new directions of action towards increasing the share of renewable energy sources.
Design/methodology/approach: The work analyzes changes in subsequent periods, compares shares in Poland with shares in the European Union, and uses an analytical model to present forecasts for the coming years.
Findings: The work identifies a growing trend in the overall share of renewable energy sources in Poland and the European Union, draws attention to Poland's low share compared to other EU countries and examines changes in the shares of individual factors in the Electricity sector.
Research limitations/implications: Based on the analysis of the energy shares from renewable sources in the Electricity sector, it seems reasonable to conduct a similar analysis for the other two sectors and link the results with changes in environmental pollution.
Practical implications: The results of the analysis may influence actions taken in Poland to increase the share of energy from renewable sources and be the basis for analysis in terms of Poland's implementation of Directive (EU) 2018/2001.
Originality/value: The article presents analyses of the share of energy from renewable sources along with forecasts for the following years, which analyses can be used by the entity responsible for implementing activities under Directive (EU) 2018/2001.
Keywords: renewable energy, forecasting, Directive (EU) 2018/2001.
Category of the paper: Research paper, general review.

1. Introduction

Energy from renewable sources, commonly referred to as renewable energy, is defined by the International Energy Agency (IEA, 2024) as "renewable energy is derived from natural processes that are replenished at a faster rate than they are consumed" (SHARES, 2023). That is energy, including non-fossil sources, using the Earth's natural resources, characterized

by renewable energy as "inexhaustible" energy sources (Szafrański, 2004). The concept of renewable energy sources is fundamental due to its appearance in EU legal acts, as well as in the legal regulations of the European Union Member States. The first definitions of renewable sources are included in 2003/54/EC, 2009/72/EC, 2001/77/EC (Pobrzeżyńska, 2020). The definition currently in force in Directive 2009/28/EC is mainly similar to that in Directive 2009/28/EC, but updated with a more precise definition and taking into account new technologies and sustainability criteria: "renewable, non-fossil energy sources including wind energy, solar radiation, aerothermal energy, geothermal energy, hydrothermal energy, hydro energy, energy of waves, sea currents and tides, ambient energy, energy obtained from biomass, biogas, agricultural biogas, biomethane, bioliquids and renewable hydrogen" (Dziennik Ustaw, 2024). Directive (EU) 2018/2001 (RED II) replaced Directive 2009/28/EC, which was in force until December 31, 2020. This directive was created due to the lack of apparent progress towards achieving the objectives in Directive 2001/77/EC and the need to combat climate change. This directive sets new goals for Member States: 20% share of renewable energy in gross energy consumption in the EU by 2020 and at least 10% of renewable energy in transport by 2020. The targets were set at the national level, and Member States could choose the means to achieve them. Directive (EU) 2018/2001 (RED II) introduced new objectives and rules for 2021-2030. RED II raised the average EU target to 32% renewable energy by 2030 and updated the methods of calculating this indicator, considering more sustainable energy sources (Dziennik Ustaw, 2024).

Due to the requirements of EU regulations, such as the Renewable Energy Directive and the need to monitor progress in achieving climate and energy goals in various sectors of the economy, the shares of energy from renewable sources have been divided into sectors such as electricity, transport, and heating and cooling (Dziennik Ustaw, 2024). The Electricity sector refers to using renewable energy sources (RES) to produce electricity. This sector's leading renewable energy sources are wind, solar, geothermal hydropower, ocean, biomass, and biogas. This sector's data is broken down into Hydro, Wind, Solar, Solid biofuels, and all other renewables. The next sector – Transport – is a key area in the energy transformation because itis responsible for a significant part of global greenhouse gas emissions. The introduction of renewable energy sources in this sector is aimed at reducing CO2 emissions, reducing pollution, and limiting mining resources. The renewable energy sources within this sector are biofuels (biodiesel, bioethanol), biogas, renewable hydrogen (green choice), and energy produced from organic and industrial waste. The third sector is Heating and Cooling, which includes heating or cooling energy production and supply. Renewable energy comes here from, among others, biomass, biogas, geothermal energy, heat pumps, solar collectors, wind turbines, and hydroelectric power plants. The Renewable Energy Directive (RED I, RED II) requirements regulate the development of renewable energy sources (RES) in the European Union. Their main goal is to promote the use of energy from renewable sources to achieve sustainable development, reduce greenhouse gas emissions, and increase energy security.

The electricity sector plays a key role in the energy transition and achieving renewable energy goals. For this reason, the study analyzed the share of renewable energy sources in Poland and the European Union. It determined the dynamics of changes in the share of renewable energy sources, taking into account the division into factors of the energy mix of the Electricity sector: wind, hydro, solar, and solar biofuels. Additionally, short-term forecasts were estimated, which may indicate actions to achieve the objectives of Directive (EU) 2018/2001. Considering these analyses will allow us to present the situation of Poland and the entire European Union in the context of the current possibilities of obtaining energy from renewable sources. It may also determine new action directions towards energy security, sustainable development, or reducing the negative environmental impact.

2. Analysis of the share of energy from renewable sources in the Electricity sector in Poland

Below is data obtained from Eurostat - the official statistical database of the European Union, which collects and provides statistical data on, among others, EU Member States. These data concern the electricity produced from renewable sources within the Electricity sector (Total (RES-E numerator)). The first part of the analysis includes data for Poland regarding the division of renewable sources within the electricity sector, the second part concerns the shares of the entire European Union, and the next part determines the location of Poland's shares in the European Union.

Table 1 presents data from 2004-2023 of the Electricity sector, divided into Hydro, Wind, Solar, Solid biofuels, and all other renewables (the data unit is ktoe, where one ktoe = 11.63 GWh).

Table 1.
The share of energy from renewable sources in the Electricity sector in Poland

	Hydro	Wind	Solar	Solid biofuels	All other renewables	Sum
2004	157.9462	10.00582	0	77.09966	7.401118	252.4528
2005	163.9889	17.47881	0	120.3654	9.5681	311.4012
2006	169.0568	27.95813	0	157.5813	13.76784	368.364
2007	172.5635	45.11882	0	202.9544	16.78538	437.4222
2008	177.9279	73.60088	0	289.1965	21.91548	562.6407
2009	182.1233	100.1006	0	421.6778	27.70482	731.6066
2010	188.7115	146.1987	0	507.7567	34.3319	876.9988
2011	191.8441	251.2468	0.015047	614.65	38.79037	1096.546
2012	193.4591	387.8161	0.098108	819.32	48.61204	1449.305
2013	195.4322	527.306	0.127429	682.0137	59.30499	1464.184
2014	197.9022	651.2055	0.592519	787.6358	70.18676	1707.523
2015	197.922	832.9722	4.870077	776.1513	77.93646	1889.852
2016	199.2501	1035.329	10.65133	594.3875	89.45168	1929.07

Cont. table 1.

2017	199.1066	1166.876	14.22726	456.4537	101.2122	1937.876
2018	200.943	1174.195	25.83732	458.5745	104.2688	1963.819
2019	200.6005	1224.5	61.10688	553.8394	106.6074	2146.654
2020	199.6951	1294.331	168.3505	596.1096	121.7237	2380.21
2021	199.8544	1422.026	338.3016	550.1651	142.9797	2653.327
2022	199.0943	1628.076	714.503	510.2406	145.9231	3197.837
2023	200.4808	1968.277	955.0377	490.5353	150.9079	3765.239

Source: https://ec.europa.eu/eurostat/web/energy/database/additional-data#Short%20assessment%20of%20renewable%20energy%20sources%20.

Based on the data presented in the table above, the share of energy from renewable sources is presented in Figure 1. On this basis, it is possible to determine the increasing trend of energy shares within the Electricity sector over the years 2004-2023.

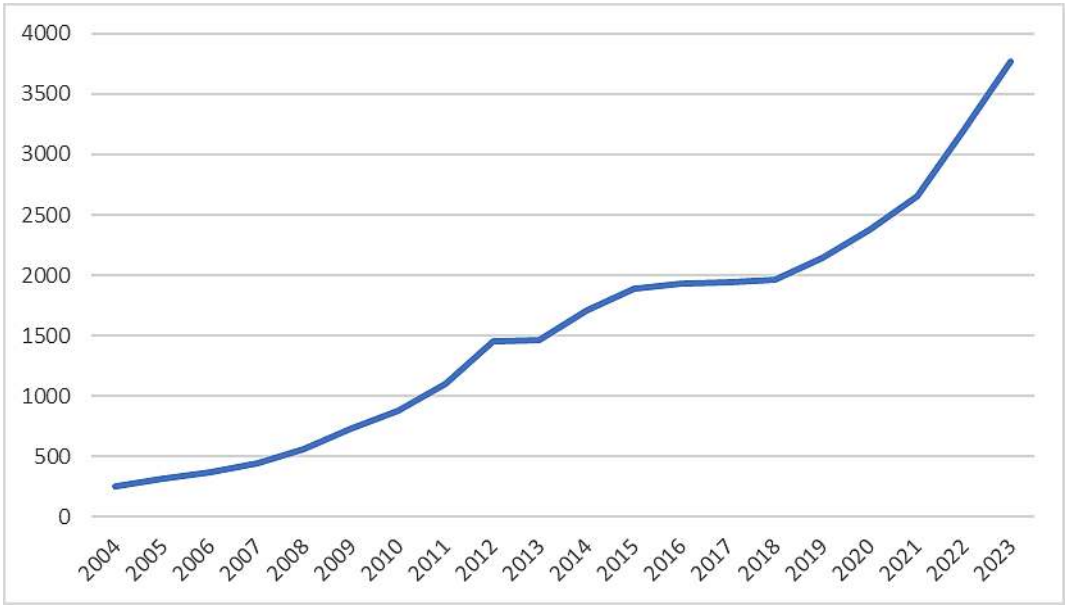

Figure 1. The share of energy from renewable sources in the Electricity sector in Poland.

Source: own study based on https://ec.europa.eu/eurostat/web/energy/database/additional-data#Short%20assessment%20of%20renewable%20energy%20sources%20.

Based on the chart above, significant increases can be observed yearly until 2012. After this period, until 2018, there was a period of slowdown in growth. Only after 2019 did the share increase return, but it was smaller than at the beginning of the analyzed period. The most significant increase in the share of energy occurred in 2019, recording an increase of 30.03% (an increase from 562.64 to 731.61 ktoe).

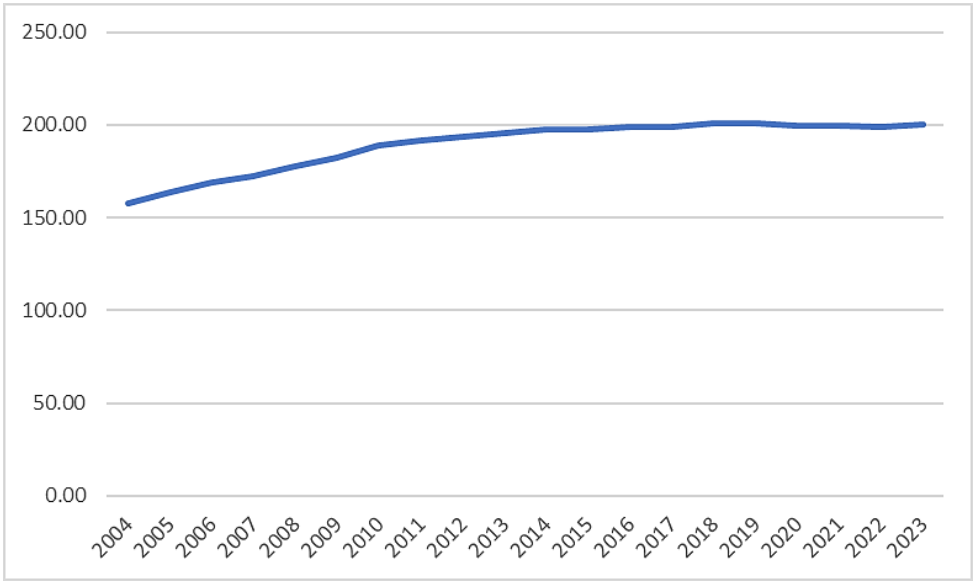

Figure 2. The share of energy from renewable sources as part of the Hydro source in Poland.

Source: own study based on https://ec.europa.eu/eurostat/web/energy/database/additional-data#Short%20assessment%20of%20renewable%20energy%20sources%20.

In the case of Hydro energy shares, from the beginning of 2023 can be observed (with a decreasing trend) until 2016. After this period, there were minimal year-to-year declines in Hydro energy shares. The most significant increase occurred in 2005 - 23.35% compared to 2004 (an increase from 157.95 to 163.99). From 2017 to 2022, there were decreases in shares or minimal increases - below 1%.

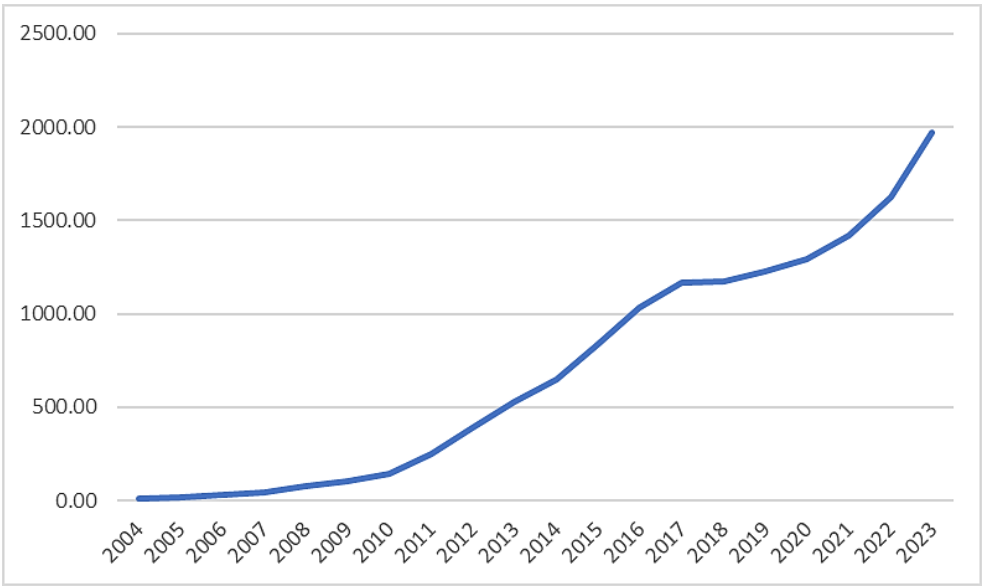

Figure 3. The share of energy from renewable sources as part of the Wind source in Poland.

Source: own study based on https://ec.europa.eu/eurostat/web/energy/database/additional-data#Short%20assessment%20of%20renewable%20energy%20sources%20.

An increase characterizes the share of energy in wind, which is quite uneven between the years 2004-2011, 2011-2018, and 2018-2023. The most significant increases can be observed in 2005 - an increase of 74.69% compared to 2004 (an increase from 10.01 to 17.48 ktoe) and

in 2011 – an increase of 71.85% in the share of energy compared to 2010 (an increase from 146.2 to 251.25 ktoe). The smallest increase took place in 2018 - an increase of 0.63% compared to 2017.

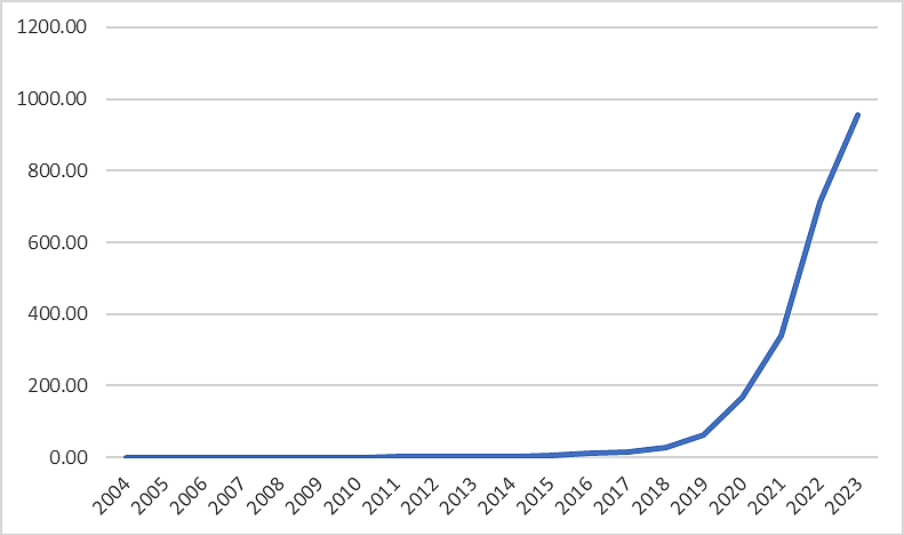

Figure 4. The share of energy from renewable sources as part of the Solar source in Poland.

Source: own study based on https://ec.europa.eu/eurostat/web/energy/database/additional-data#Short%20assessment%20of%20renewable%20energy%20sources%20.

The shares of energy from renewable sources under Solar were zero until 2010; the first indications of obtaining energy from this source were recorded only in 2011. A share increase can be observed during this period - from 0 in 2010 to 995.04 ktoe in 2023.

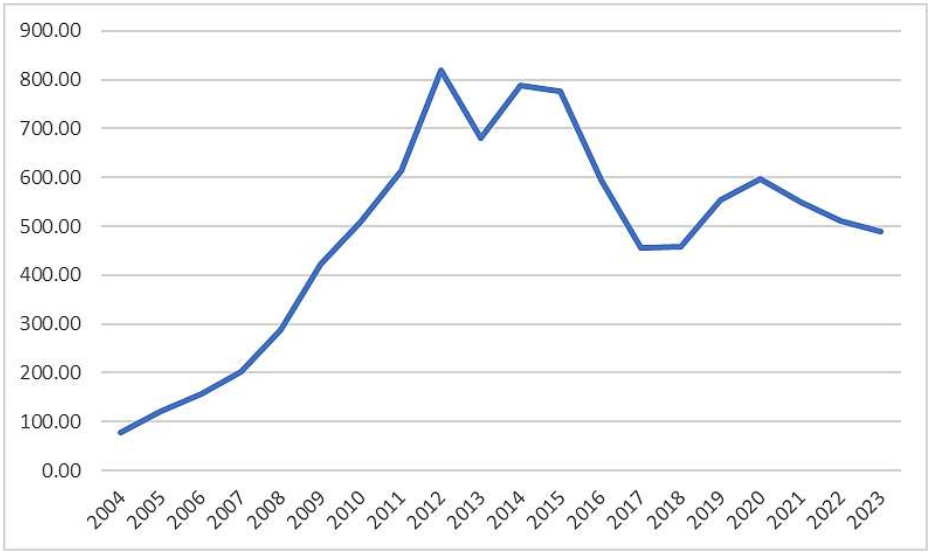

Figure 5. The share of energy from renewable sources solid biofuels in Poland.

Source: *own study based on* https://ec.europa.eu/eurostat/web/energy/database/additional-data#Short%20assessment%20of%20renewable%20energy%20sources%20.

The graph of the energy share from Solid biofuels shows an increase, reaching its maximum value in 2012 (819.32 ktoe). After this period, the energy share values started to decline and then stabilized with some fluctuations. The largest increase took place in 2005—an increase of 56.12% compared to 2004. The largest decrease in energy from Solid biofuels was recorded in 2016 - 23.42% compared to 2015.

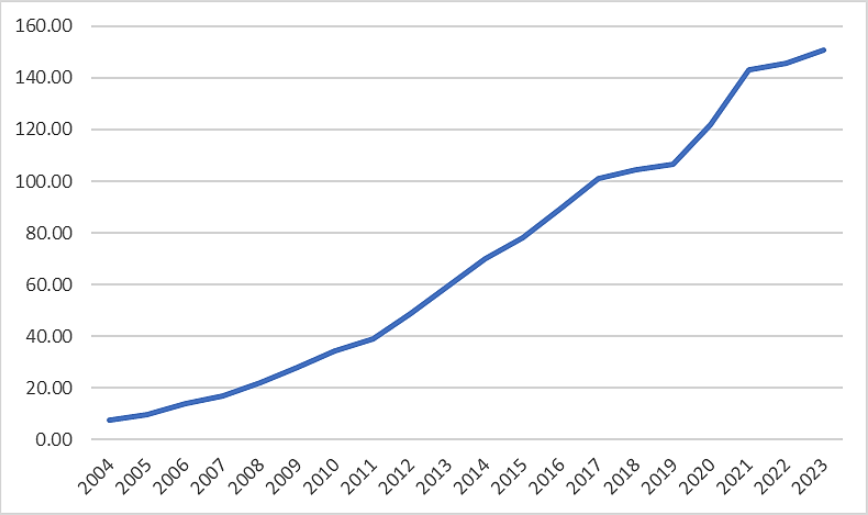

Figure 6. The share of energy from renewable sources as part of the All other renewable sources in Poland.

Source: own study based on https://ec.europa.eu/eurostat/web/energy/database/additional-data#Short%20assessment%20of%20renewable%20energy%20sources%20.

All other renewable energy shares are characterized by a gradual and quite regular increase from 7.40 to 150.91 ktoe. The largest increase took place in 2006—an increase of 43.89% compared to 2005.

Table 2 presents the shares of energy from renewable sources, divided into components of the electricity sector, and the estimated percentage changes from year to year are prese ted. The presented results can be used for a broader analysis compared to the analysis in Figure 1-6.

Table 2.
Values of shares of energy from renewable sources, along with the percentage change from year to year, divided into factors of the Electricity sector in Poland

Year	Electricity	percentage change	Hydro	percentage change	Wind	percentage change	Solar	percentage change	Solid biofuels	percentage change	All other renewables	percentage change
2004	252.45	-	157.95	-	10.01	-	0.00	-	77.10	-	7.40	-
2005	311.40	23.35%	163.99	3.83%	17.48	74.69%	0.00	-	120.37	56.12%	9.57	29.28%
2006	368.36	18.29%	169.06	3.09%	27.96	59.95%	0.00	-	157.58	30.92%	13.77	43.89%
2007	437.42	18.75%	172.56	2.07%	45.12	61.38%	0.00	-	202.95	28.79%	16.79	21.92%
2008	562.64	28.63%	177.93	3.11%	73.60	63.13%	0.00	-	289.20	42.49%	21.92	30.56%
2009	731.61	30.03%	182.12	2.36%	100.10	36.00%	0.00	-	421.68	45.81%	27.70	26.42%
2010	877.00	19.87%	188.71	3.62%	146.20	46.05%	0.00	-	507.76	20.41%	34.33	23.92%
2011	1096.55	25.03%	191.84	1.66%	251.25	71.85%	0.02	-	614.65	21.05%	38.79	12.99%
2012	1449.31	32.17%	193.46	0.84%	387.82	54.36%	0.10	552.00%	819.32	33.30%	48.61	25.32%
2013	1464.18	1.03%	195.43	1.02%	527.31	35.97%	0.13	29.89%	682.01	-16.76%	59.30	22.00%

Cont. table 2.

2014	1707.52	16.62%	197.90	1.26%	651.21	23.50%	0.59	364.98%	787.64	15.49%	70.19	18.35%
2015	1889.85	10.68%	197.92	0.01%	832.97	27.91%	4.87	721.93%	776.15	-1.46%	77.94	11.04%
2016	1929.07	2.08%	199.25	0.67%	1035.33	24.29%	10.65	118.71%	594.39	-23.42%	89.45	14.78%
2017	1937.88	0.46%	199.11	-0.07%	1166.88	12.71%	14.23	33.57%	456.45	-23.21%	101.21	13.15%
2018	1963.82	1.34%	200.94	0.92%	1174.20	0.63%	25.84	81.60%	458.57	0.46%	104.27	3.02%
2019	2146.65	9.31%	200.60	-0.17%	1224.50	4.28%	61.11	136.51%	553.84	20.77%	106.61	2.24%
2020	2380.21	10.88%	199.70	-0.45%	1294.33	5.70%	168.35	175.50%	596.11	7.63%	121.72	14.18%
2021	2653.33	11.47%	199.85	0.08%	1422.03	9.87%	338.30	100.95%	550.17	-7.71%	142.98	17.46%
2022	3197.84	20.52%	199.09	-0.38%	1628.08	14.49%	714.50	111.20%	510.24	-7.26%	145.92	2.06%
2023	3765.24	17.74%	200.48	0.70%	1968.28	20.90%	955.04	33.66%	490.54	-3.86%	150.91	3.42%

Source: own study based on https://ec.europa.eu/eurostat/web/energy/database/additional-data#Short%20assessment%20of%20renewable%20energy%20sources%20.

Based on the data presented in Table 1, forecasts for the share of energy from renewable sources in the Electricity sector were estimated for the following years. Due to the upward nature of the time series, an analytical model is presented. In order to compare the results, the analysis was based on five functions: linear, polynomial, power, logarithmic, and exponential. In the further part of the analysis, the error values described by the formulas were determined (1)-(4) (Zeliaś, Pawełek, Wanat, 2022).

a) Mean Absolute Error

$$\boldsymbol{MAE = \frac{1}{n} \cdot \sum_{i=1}^{n} |y_t - \hat{y}_t|} \tag{1}$$

b) Mean Absolute Percentage Error

$$\boldsymbol{MAPE = \frac{1}{n} \cdot \sum_{i=1}^{n} \left| \frac{y_t - \hat{y}_t}{y_t} \right| \cdot 100\%} \tag{2}$$

c) Root Mean Squared Error

$$\boldsymbol{RMSE = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} (y_t - \hat{y}_t)^2}} \tag{3}$$

d) Root mean Squared Percentage Error

$$\boldsymbol{RMSPE = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} \left(\frac{y_t - \hat{y}_t}{y_t} \right)^2} \cdot 100\%} \tag{4}$$

Table 3 below presents the values of the estimated forecasts for 2024-2028, the error values of these forecasts, the standard error of model estimation, and the coefficient of determination.

Table 3.

Forecasted values of energy shares from renewable sources along with estimated errors, standard error of model estimation, coefficient of determination for Poland

	Linear model	**Polynomial model**	**Power model**	**Logarithmic model**	**Exponential model**
Trend function	$\hat{y} = 163.17x - 157.13$	$\hat{y} = 3.91 \cdot x^2 + 81.14x + 143.63$	$\hat{y} = 155.47x^{0.97}$	$\hat{y} = 1062.8 \ln(x) - 693.6$	$\hat{y} = 301.25 \cdot e^{0.132x}$
Forecast 2024	3269.360	3570.121	2953.824	2542.120	4814.083
Forecast 2025	3432.526	3819.219	3089.754	2591.561	5493.225
Forecast 2026	3595.692	4076.129	3225.480	2638.804	6268.178
Forecast 2027	3758.858	4340.851	3361.012	2684.037	7152.456
Forecast 2028	3922.024	4613.385	3496.359	2727.422	8161.483
MAE	163.520	147.332	168.264	358.914	262.033
MAPE	15.72%	9.85%	13.41%	47.75%	18.00%
RMSE	218.898	185.807	266.016	473.682	317.827
RMSPE	26.18%	11.11%	17.63%	93.01%	19.87%

Cont. table 3.

Standard error of model estimation	230.739	201.535	280.405	499.305	335.019
Coefficient of determination	0.9487	0.963	0.9469	0.7595	0.9343

Source: own study based on https://ec.europa.eu/eurostat/web/energy/database/additional-data#Short%20assessment%20of%20renewable%20energy%20sources%20.

Based on the estimated forecast errors, the polynomial model shows the minor errors for all measures: MAE = 147.332 ktoe (the forecast values differ on average by about 147.332 ktoe from the actual values), MAPE = 9.85% (the average forecast error of the model is approximately 9.85% of the actual energy share values), RMSE = 185.807 ktoe (on average, the forecasts differ from the actual values by approximately 185.807 ktoe), RMSPE = 11.11% (on average, this model's forecasts differ from the actual values by 11.11%), which suggests that it fits the data best. In terms of the MAE error and RMSE error values, the linear model obtained the second lowest value - MAE = 163.52, RMSE = 218.898, and the power model had the third lowest value - MAE = 168.264, RMSE = 266.016. Due to the MAPE and RMSPE error, the second smallest value was obtained for the power model: MAPE = 13.41%, RMSPE = 17.63%, while the third smallest value of the MAPE and RMSPE error was obtained for the linear model: MAPE = 15.72%, RMSPE = 26.18%. The logarithmic and exponential models obtained the poorest results due to the errors adopted for model evaluation, the standard error of model estimation, and the coefficient of determination.

3. Analysis of the share of energy from renewable sources in the Electricity sector in the European Union

The rest of the article is devoted to analyzing the shares of energy from renewable sources in the Electricity sector throughout the European Union. Table 4 below presents the share of individual energy sources within the analyzed Electricity sector.

Table 4.
The share of energy from renewable sources in the Electricity sector in UE

Year	Hydro	Wind	Solar	Solid biofuels	All other renewables	Sum
2004	29209.01	4783.324	59.40782	3116.968	1936.829	39105.54
2005	29309.81	5733.508	125.4246	3489.555	2263.442	40921.74
2006	29180.54	6783.305	214.0559	3883.316	2649.352	42710.57
2007	29259.99	8180.863	324.5509	4098.627	3183.681	45047.72
2008	29202.98	9568.501	639.5203	4572.556	3534.408	47517.97
2009	29308.17	10978.45	1212.724	4930.917	3945.422	50375.68
2010	29628.52	12442.35	1996.91	5587.447	4530.596	54185.83
2011	29632.79	13968.62	4066.082	5772.239	5012.31	58452.04
2012	29507.67	15574.03	6034.099	6196.926	5760.286	63073.01
2013	29516.8	17280.99	7231.683	6062.111	6439.401	66530.98

Cont. table 4.

2014	29462.78	18995.78	8097.036	6080.291	6906.297	69542.18
2015	29663.73	21455.14	8672.237	6194.86	7262.37	73248.33
2016	29596.59	23384.59	8687.407	6223.371	7392.303	75284.26
2017	29462.59	25710.3	9280.453	6385.329	7459.23	78297.89
2018	29559.81	27524.33	9718.66	6556.527	7447.706	80807.04
2019	29509.63	29954.82	10643.44	6926.871	7460.777	84495.53
2020	29685.34	32367.68	12465.55	7139.495	7512.742	89170.81
2021	29817.04	34930.84	14123	7499.54	7651.319	94021.73
2022	29673.64	37263.96	18106.02	6869.266	7465.675	99378.56
2023	27724.68	38256.98	20801.75	5590.294	6813.437	99187.14

Source: https://ec.europa.eu/eurostat/web/energy/database/additional-data#Short%20assessment%20of% 20renewable%20energy%20sources%20.

Figure 7 presents the total share of energy from renewable sources. Visual analysis allows us to determine the increasing nature of the energy share over the years 2004 - 2023, with some random fluctuations.

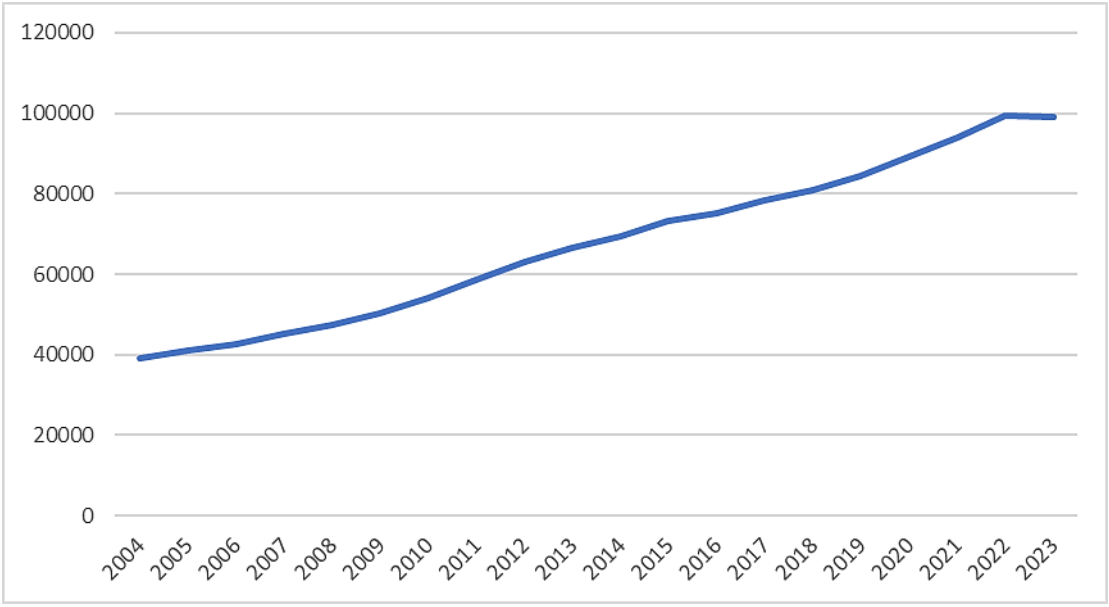

Figure 7. The share of energy from renewable sources in the Electricity sector in UE.

Source: *own study based on* https://ec.europa.eu/eurostat/web/energy/database/additional-data#Short% 20assessment%20of%20renewable%20energy%20sources%20.

Based on the visual assessment and determining the increasing nature of the data, an analytical model was proposed to forecast the share of energy from renewable sources in the Electricity sector for the years 2024-2028. The analysis was based on five functions: linear, polynomial, power, logarithmic, and exponential. Table 5 presents the calculated forecast values based on the mentioned trend line functions, error values, standard error of model estimation, and coefficient of determination.

Table 5.
Forecasted values of the shares of energy from renewable sources within the Electricity sector along with estimation errors, standard error of model estimation, and coefficient of determination for the EU

	Linear model	**Polynomial model**	**Power model**	**Logarithmic model**	**Exponential model**
Trend function	$\hat{y} = 3342.6x + 32470$	$\hat{y} = 28.274x^2 + 2748.9x + 34647$	$\hat{y} = 30447x^{0.35}$	$\hat{y} = 22190\ln(x) + 20596$	$\hat{y} = 37712 \cdot e^{0.05x}$
Forecast 2024	102665.377	104842.457	90057.249	88154.332	111050.566
Forecast 2025	106008.010	108807.113	91561.972	89186.612	116911.173
Forecast 2026	109350.644	112828.317	93023.280	90172.998	123081.070
Forecast 2027	112693.277	116906.068	94444.235	91117.397	129576.578
Forecast 2028	116035.910	121040.366	95827.566	92023.237	136414.882
MAE	1217.811	1124.493	4726.478	6650.212	1759.675
MAPE	2.08%	1.80%	7.53%	11.26%	2.60%
RMSE	1530.827	1281.294	5864.219	8055.092	2253.087
RMSPE	2.84%	2.10%	9.38%	15.09%	3.08%
Standard error of model estimation	1613.634	1389.759	6181.430	8490.813	2374.963
Coefficient of determination	0.9937	0.9956	0.8956	0.8264	0.9893

Source: *own study based on* https://ec.europa.eu/eurostat/web/energy/database/additional-data#Short%20assessment%20of%20renewable%20energy%20sources%20.

Analyzing the values of the errors obtained, the polynomial model shows the best fit: MAE = 1124.493 ktoe (the predicted values differ on average by about 1124.493 ktoe from the actual values), MAPE = 1.80% (the average error of the model forecasts is about 1.80% of the actual values of the energy share, this is very low error rate, suggesting that this model's predictions are accurate), RMSE = 1281.294 ktoe (on average, the forecasts differ from the actual values by approximately 1281.294 ktoe) and RMSPE = 2.10% (the forecasts of this model on average differ from the actual values by 2.10% - a very low level of error). Guided by the error minimization criterion, the forecast values of the share of energy from renewable sources within the Electricity sector are: 104842.457 ktoe (2024), 108807.113 ktoe (2025), 112828.317 ktoe (2026), 116906.068 ktoe (2027), 121040.366 ktoe (2028). The second model with the lowest error value is the linear model with error values at the following levels: MAE = 1217.811, MAPE = 2.08%, RMSE = 1530.827 and RMSPE = 2.84%. The third model with the most minor errors is the exponential model: MAE = 1759.675, MAPE = 2.60%, RMSE = 2253.087 and RMSPE = 3.08%. The logarithmic model achieved the highest error values.

Table 6.
The relative share of energy obtained from renewable sources in Poland to the share of energy obtained in the EU

	Hydro	Wind	Solar	Solid biofuels	All other renewables
2004	0.541%	0.209%	0.000%	2.474%	0.382%
2005	0.560%	0.305%	0.000%	3.449%	0.423%
2006	0.579%	0.412%	0.000%	4.058%	0.520%
2007	0.590%	0.552%	0.000%	4.952%	0.527%
2008	0.609%	0.769%	0.000%	6.325%	0.620%
2009	0.621%	0.912%	0.000%	8.552%	0.702%
2010	0.637%	1.175%	0.000%	9.087%	0.758%
2011	0.647%	1.799%	0.000%	10.648%	0.774%
2012	0.656%	2.490%	0.002%	13.221%	0.844%
2013	0.662%	3.051%	0.002%	11.250%	0.921%
2014	0.672%	3.428%	0.007%	12.954%	1.016%
2015	0.667%	3.882%	0.056%	12.529%	1.073%
2016	0.673%	4.427%	0.123%	9.551%	1.210%
2017	0.676%	4.539%	0.153%	7.148%	1.357%
2018	0.680%	4.266%	0.266%	6.994%	1.400%
2019	0.680%	4.088%	0.574%	7.996%	1.429%
2020	0.673%	3.999%	1.351%	8.349%	1.620%
2021	0.670%	4.071%	2.395%	7.336%	1.869%
2022	0.671%	4.369%	3.946%	7.428%	1.955%
2023	0.723%	5.145%	4.591%	8.775%	2.215%

Source: *own study based on* https://ec.europa.eu/eurostat/web/energy/database/additional-data#Short%20assessment%20of%20renewable%20energy%20sources%20

Below, in Figure 8, Poland's share in energy obtained from renewable sources in the Electricity sector, divided into energy sources, is visualized compared to the entire EU. The relative share of Poland's energy from the hydro source increased in subsequent years of the analyzed period, but it did not exceed 0.8% in any year (the largest share in 2023 at 0.723%). Poland's share of wind sources also shows an upward trend, but it is characterized by a higher percentage share: from 0.209% in 2004 to 5.145% in 2023. Obtaining energy from solar sources in Poland looks unfavorable because the energy level will be zero by 2010. After this period, there was an increase to 4.591% in 2023 (slightly less than the Wind source). The percentage share of energy from solid biofuels varies significantly. After an increase of 12.954% in 2014, it decreased to 9.551%, and the relative share remained at 6.994% - 8.775%. The relative share of energy from All other renewables showed an increasing trend, reaching the highest percentage level of 2.215%. It seems reasonable to extend the analysis of the achieved shares of energy from renewable sources about the actions taken or changes introduced by the authorities dealing with energy in Poland in order to better determine the trend in changes in the amount of energy obtained.

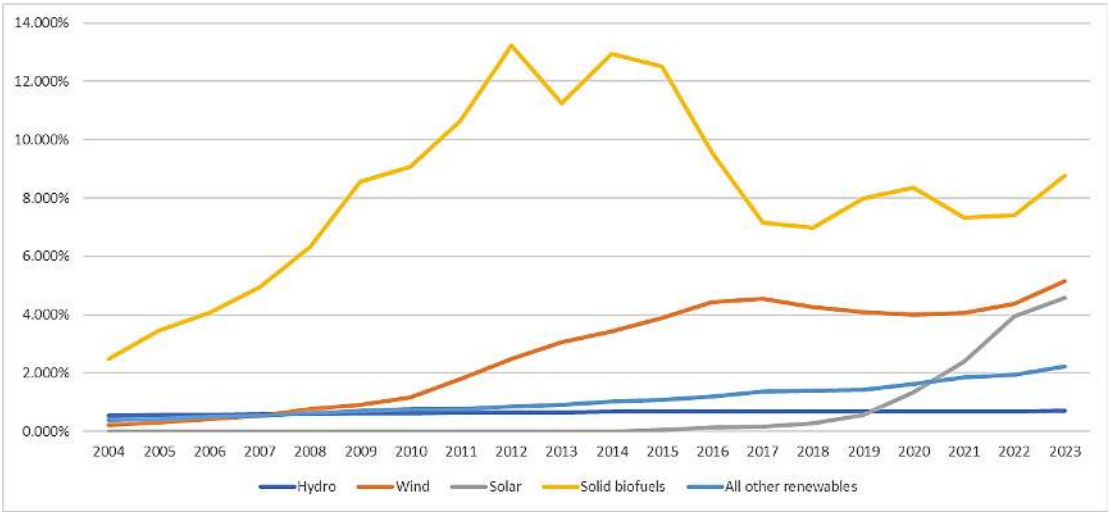

Figure 8. The relative share of energy obtained from renewable sources in Poland to the share of energy obtained in the EU.

Source: *own study based on* https://ec.europa.eu/eurostat/web/energy/database/additional-data#Short%20assessment%20of%20renewable%20energy%20sources%20.

4. Summary

Poland and the European Union consistently increase their share of renewable energy in the electricity sector. The analysis of the share of energy in Poland within RES indicates an increase in the share in hydro, wind, solar, and only solid biofuels after 2012, continuing the downward trend until 2017 and remaining at this level until 2023. Poland's share compared to the European Union:

- Poland took 10th place in the relative share of energy within the Electricity sector at the level of 2.82% (the most significant shares were Germany 22.83%, Spain 11.44% and France 11.44%),
- in 2022, Poland ranked 9th with a relative share of 3.22% (the most significant shares were Germany 22.61%, Spain 11.81% and France 11.43%),
- in 2023, Poland was in 8th place with a share of 3.8% (the most significant shares were Germany 23.35%, Spain 13.12% and France 12.21%).

For Poland to improve its situation in the context of renewable energy, it should take specific actions in various areas of energy, regulatory and investment policy, and the development of new technologies. It should also consider financial support and education.

References

1. Acedański, J., Hadaś-Dyduch, M., Szkutnik, W. (2016). *Prognozowanie zjawisk ekonomicznych i finansowych. Część 1. Prognozowanie z Excelem*. Katowice: Wydawnictwo Uniwersytet Ekonomiczny w Katowicach.
2. Brodziński, Z., Kramarz, M., Sławomirski, M.R. (Eds.) (2016). *Energetyka odnawialna wizytówką nowoczesnej gospodarki.* Toruń: Adam Marszałek.
3. Bukowski, M. (2012). *Efektywność ekonomiczna produkcji energii w małych elektrowniach wodnych.* Raszyn: ITP.
4. Dubel, A. (2016). Klasyfikacje kosztów zapobiegania zmianom klimatu i adaptacja do nich oraz ich znaczenie dla podejmujących strategiczne decyzje. In: T. Walczykiewicz (Ed.), *Problemy planowania w gospodarce wodnej i oceny stanu hydromorfologicznego rzek*. Warszawa: IMGW-PIB.
5. EUR-Lex (2024). Retrieved from: https://eur-lex.europa.eu/legal-content/PL/TXT/PDF/?uri=CELEX%3A32009L0028.
6. *IEA* (2024). Retrieved from: https://www.iea.org.
7. Jabłoński, W., Wnuk, J. (2004). *Odnawialne źródła energii w polityce energetycznej Unii Europejskiej i Polski. Efektywne zarządzanie inwestycjami - studia przypadków*. Sosnowiec: Wydawnictwo Wyższej Szkoły Zarządzania i Marketingu w Sosnowcu.
8. Kundzewicz, Z., Hov, O., Okruszko, T. (Eds.) (2017). *Zmiany klimatu i ich wpływ na wybrane sektory w Polsce*. Poznań: Instytut Środowiska Rolniczego i Leśnego Polskiej Akademii Nauk.
9. Kurałowicz, Z. (Ed.) (2012). *Techniczne aspekty ochrony środowiska. Woda źródłem energii.* Gdańsk: Wydawnictwo Politechniki Gdańskiej.
10. Nazarko, J. (Eds.) (2018). *Prognozowanie w zarzadzaniu przedsiębiorstwem. Cz. IV. Prognozowanie na podstawie modeli trendu*. Białystok: Oficyna Wydawnicza Politechniki Białostockiej.
11. Obwieszczenie Marszałka Sejmu Rzeczypospolitej Polskiej z dnia 19.08.2024 r. w sprawie ogłoszenia jednolitego tekstu ustawy o odnawialnych źródłach energii. Dziennik Ustaw, Poz. 1361 (2024). Retrieved from: https://dziennikustaw.gov.pl/D2024000136101.pdf
12. Pietkun-Greber, I., Ratuszny, P. (Eds.) (2017). *Odnawialne źródła energii. Teoria i praktyka. Tom II*. Brzesko: COTI Conference Time Stanisław Kurtyka.
13. Pobrzeżyńska, M. (2020). *Pomoc państwa na produkcję energii ze źródeł odnawialnych w prawie Unii Europejskiej*. Warszawa: C.H. Beck.
14. SHARES (2024). Retrieved from: https://ec.europa.eu/eurostat/web/energy/database/additional-data#Short%20assessment%20of%20renewable%20energy%20sources%20.
15. Słodczyk, E. (2017). Funkcjonowanie elektrowni geotermalnych oraz ich wpływ na środowisko przyrodnicze na przykładzie elektrowni działających na Islandii. In: I. Pietkun-

Greber, P. Ratuszny (Eds.), *Odnawialne źródła energii. Teoria i praktyka. Tom II*. Brzesko: COTI Conference Time Stanisław Kurtyka.

16. Surmacz, B., Paszkowski, M. (Eds.) (2023). *Raport. Bezpieczeństwo energetyczne państwa Europy Środkowej i Wschodniej*. Lublin: Instytut Europy Środkowej.
17. Szafrański, A. (2004). *Prawo energetyczne. Wartości i instrumenty ich realizacji.* Warszawa: C.H. Beck.
18. Wiśniewski, J.W. (2020). *Prognozowanie z wielorównaniowych mikromodeli ekonometrycznych.* Toruń: Wydawnictwo Naukowe Uniwersytetu Mikołaja Kopernika.
19. Zeliaś, A., Pawełek, B., Wanat, S. (2022). *Prognozowanie ekonomiczne. Teoria, przykłady, zadania.* Warszawa: PWN.

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A GREEN APPROACH ON RISK MANAGEMENT: EXPLORING CONSTRUCTS IN A CONCEPT MAPPING FRAMEWORK

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Purpose: The study aims to explore the constructs within concept mapping related to the concept of green risk management and to assess the chronological development of this academic discussion through the analysis of bibliographic data.
Design/methodology/approach: Using SciMAT software, a systematic review was conducted of 493 academic articles in the Scopus database, selected according to the PRISMA statement guidelines and published between 2000 and 2024.
Findings: The study reveals a growing academic interest in green risk management, particularly in integrating environmental, social, and governance (ESG) factors into traditional risk frameworks. Key research themes identified include sustainable supply chains, green building, ESG-focused investment, and public sector financial risk management. The analysis highlights a substantial rise in both publication and citation rates on these topics over the past five years, signaling their importance in risk management discourse.
Research limitations/implications: The field remains at an early development stage, with theoretical foundations not yet fully established. The research gap points to opportunities for future studies, specifically in systematizing theories and creating robust models that integrate environmental and social considerations within risk management frameworks.
Practical implications: Findings underscore the necessity for businesses to implement proactive risk management strategies, especially in supply chain sustainability, green construction, and ESG investments. The study suggests that regulatory frameworks and automated supplier risk assessments are critical for enhancing resilience and meeting stakeholder expectations.
Social implications: By promoting a holistic view of risk that includes social and environmental dimensions, the research may guide corporate social responsibility (CSR) and public policies, fostering greater transparency and environmental accountability. This shift in risk management could encourage sustainable practices that improve quality of life and align with societal values.
Originality/value: The paper contributes novel insights by tracking the thematic evolution of green risk management, offering value to academics and practitioners in finance, management, and sustainability. The use of SciMAT software provides an innovative method for visualizing thematic development, making this research a valuable resource for understanding the maturation of green risk management.
Keywords: Risk management, Sustainable Development, Bibliometric analysis, Systematic literature review, Scopus.
Category of the paper: Research paper.

1. Introduction

The integration of sustainability into an organization's risk management framework is increasingly recognized as a critical factor in achieving long-term viability and resilience. As organizations face a growing array of environmental, social, and governance (ESG) risks, traditional risk management paradigms must evolve to incorporate sustainability considerations. This evolution is driven by the need to address a broader spectrum of risks that not only threaten financial performance but also impact social and environmental outcomes. Sustainability acts as a catalyst for enhancing risk management practices by necessitating a more comprehensive risk identification process. According to Haywood, sustainability encourages organizations to identify, quantify, and manage risks that extend beyond conventional financial metrics, integrating environmental and social impacts into the risk assessment framework (Haywood, 2021). This perspective is supported by Gomez-Valencia et al., who emphasize the importance of stakeholder perspectives in risk management, advocating for a communicative approach that considers the broader implications of sustainability (Gomez-Valencia et al., 2021). Moreover, the incorporation of sustainability into risk management practices can lead to improved organizational performance. Lambert's study highlights that effective risk communication and reporting are essential for enhancing sustainability performance within manufacturing projects (Lambert, 2023). This aligns with findings from Krysiak, who posits that risk management tools can be effectively aligned with sustainability objectives, thereby fostering a culture of ethical responsibility and proactive risk mitigation (Krysiak, 2009). The integration of sustainability criteria into risk management not only enhances risk prediction but also supports better decision-making processes, as illustrated by Weber et al., who discuss the benefits of including sustainability risks in credit risk assessments (Weber et al., 2008). The relationship between sustainability and risk management is further reinforced by the need for organizations to engage with their supply chains. As noted by Hofmann et al., managing supply chain sustainability risks requires a proactive approach to identifying social and ecological issues that could provoke stakeholder backlash (Hofmann et al., 2013). This proactive stance is echoed by Bakhtawar et al., who argue that extending risk identification to encompass environmental and social risks is vital for project management in sustainability contexts (Bakhtawar et al., 2021). The emphasis on stakeholder engagement and the recognition of the interconnectedness of risks across the supply chain underscore the necessity for organizations to adopt a holistic view of risk management that aligns with sustainability goals. In conclusion, the integration of sustainability into risk management is not merely a trend but a fundamental shift in how organizations approach risk. By recognizing the multifaceted nature of risks associated with sustainability, organizations can enhance their resilience and ensure long-term success. This integration facilitates a more comprehensive understanding of risks, promotes stakeholder engagement, and ultimately leads to improved sustainability performance across various sectors.

A green approach to risk management in the context of sustainability encompasses the integration of environmental and social considerations into traditional risk management frameworks. This approach recognizes that risks are not solely financial but also encompass ecological and social dimensions, which are increasingly critical in today's business environment. The incorporation of sustainability into risk management practices allows organizations to address stakeholder concerns, comply with regulatory requirements, and enhance their long-term viability. One of the primary drivers for adopting a green approach to risk management is the pressure from stakeholders, including consumers, investors, and non-governmental organizations (NGOs), who demand greater accountability regarding environmental and social impacts (Freise, Seuring, 2015). Companies that fail to manage these risks may face reputational damage, legal challenges, and financial losses. For instance, Freise and Seuring highlight that stakeholder management is essential for sustainable supply chain management, indicating that environmental and social risks must be prioritized alongside economic objectives (Freise, Seuring, 2015). This sentiment is echoed by Weber, who emphasizes the importance of integrating environmental credit risk indicators into financial assessments, thereby enhancing transparency and accountability in risk management processes (Weber, 2011). Furthermore, the concept of sustainability risk management (SRM) extends traditional enterprise risk management (ERM) frameworks by focusing specifically on environmental and social responsibility risks (Aziz et al., 2016). This integration is crucial as it allows organizations to identify, assess, and mitigate risks that could adversely affect their sustainability goals. For example, Dobler et al. argue that effective environmental risk management is not merely about compliance but also about achieving superior environmental performance, which is increasingly linked to overall business success (Dobler et al., 2012). This perspective is supported by Xue et al., who found that corporate environmental performance significantly influences firm risk, particularly in industries with substantial environmental impacts (Xue et al., 2019). The implementation of a green approach to risk management also involves the development of comprehensive frameworks that facilitate the identification and assessment of sustainability risks. For instance, Eller et al. propose a method for multidimensional risk identification that disaggregates complex cause-effect relationships into manageable components, allowing for more effective risk analysis in urban water systems (Eller et al., 2016). Similarly, Shao et al. discuss an integrated environmental risk assessment model that addresses various stages of risk management in the chemical industry, highlighting the importance of systematic approaches to managing environmental risks (Shao et al., 2013). In conclusion, a green approach to risk management is essential for organizations aiming to achieve sustainability in their operations. By integrating environmental and social considerations into risk management frameworks, companies can better respond to stakeholder demands, enhance their reputational capital, and ensure long-term viability. This approach not only mitigates risks but also positions organizations to capitalize on opportunities associated with sustainable practices.

Despite the growing interest in green approaches to risk management, there are few academic studies that synthesise the existing body of work in this area, which represents a research gap. With this in mind, the aim of this study is to explore the constructs within concept mapping related to the concept of green risk management and to assess the chronological development of this academic discussion through the analysis of bibliographic data. The study combines bibliometric results and scientific map analysis of 493 articles retrieved from Scopus databases and published in the last 5 years. SciMAT software was used to analyse changes in five consecutive time periods and to show the thematic evolution of the field. This study aims to contribute to the existing body of knowledge on green risk management approach, which has been reviewed in a limited manner thus far (Nyugen, Macchion, 2023, Sipa, Sitek 2024). The aim of this study is to fill previously identified research gaps and contribute to the development of research on green approaches to risk management by:

- to provide a broader perspective on risk management research in the context of sustainable (green) approaches by creating relevant research databases and multifaceted analysis,
- to methodically identify and highlight analysis periods to show the different stages of research development,
- to clearly identify the themes of popular research during each period,
- to measure the strength of connections between themes during each period.

It traces the growth trajectory of this research field, guided by the following research questions:

This study aims to answer the following research questions:

1. What is the size and growth trajectory of the field of green risk management (GRM)?
2. What is the nature of the GRM field in terms of 'performance outcomes', i.e. impact of citations, most influential authors, journals and publications?
3. How do distinctive, emerging and disappearing themes change over time?
4. How have conceptual and thematic threads evolved over time?

The current study adds several original elements to the existing body of knowledge. Firstly, this analysis focused exclusively on research addressing green approaches to risk management in the areas of management and finance, rather than the field of science as a whole. Thus, the approach taken in this way may produce more focused and complementary results.

Furthermore, this study uses SciMAT software to conduct the analysis. Compared to other analytical tools used, such as CiteSpace or VOSViewer, SciMAT is able to reveal the thematic landscape of a given research field at different periods of its development. These results are also presented in four different categories according to the strength of their impact on the development of research in a given period. In addition, SciMAT reveals sub-themes related to the main themes and thus offers a more meaningful understanding of their scope and development. More importantly, SciMAT can identify the thematic evolution of the field,

illuminating the trends and connections of themes in different periods on a single map, which sets this software apart from others.

2. Methods

This research adopts a multi-faceted approach to explore the constructs of risk management from green perspective as a concept mapping framework. This analysis employs the concept mapping technique, a well-established method for visualizing conceptual structures and relationships. The study uses several tools and methods. First, abstracts and citations are searched in leading databases of peer-reviewed scientific publications (e.g. Scopus). The decision was taken to concentrate the study on the analysis of data from the SCOPUS database, given that it indexes a greater number of journals in the fields of management, economics and finance than other databases, such as Web of Science. In order to identify the most recent trends, a temporal limitation was imposed, restricting the search to articles published in the last five years. In order to extract relevant articles that directly relate to risk management in the context of the green approach, the data search was initially guided by the titles, abstracts and keywords of the articles, with the objective of focusing the search on keywords in the next step. The search was conducted according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Page et al., 2020). The bibliometric dataset was selected by searching for the terms 'risk management' and 'sustainability' or 'green'. The author's dataset was then analysed using the specialist scientific mapping software SciMAT (v1.1.04). It should be noted that this study focuses on knowledge mapping as a distinct approach from a systematic literature review. The methodologies employed in scientific mapping encompass co-citation analysis, co-expression analysis and the examination of collaborative networks. These techniques facilitate the construction of a comprehensive representation of the scientific landscape (Gonzales-Aguilar, 2023; Cobo et al., 2011). The creation of visual representations through scientific mapping enables the illustration of intricate relationships and trends within a given field. This facilitates the identification of areas of interest and potential avenues for further research (Martins et al., 2022; Cobo et al., 2012). Although the SciMAT software is not among the most widely used bibliometric mapping tools (these include VOSviewer, CiteSpace and Bibliometrix (Tomaszewski, 2023; Colina Vargas et al., 2022; Gorzeń-Mitka, Wieczorek-Kosmala, 2024), it has been found to be particularly useful for exploring and tracking the process of research development, as it is the only open access software of its kind that allows the evolutionary exploration of research. It also stands out, among other things, for the versatility of its database preprocessing options (available methods for deduplication process, time slice, stop words and data editing) (Moral-Muñoz et al., 2020).

3. Results

The analysis of the bibliometric data reveals several key insights on the development of research on green approaches to risk management. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram in Figure 1 illustrates the process of building a knowledge base of constructs related to risk management in the context of sustainability and green approaches. An initial search was conducted in May 2024, resulting in the retrieval of 93 556 documents. The criteria for the inclusion of documents for further analysis from this extensive collection were based on those illustrated in Figure 1. Finally, in the process of mapping knowledge on green approaches in risk management, data on 493 scientific papers was used for analysis.

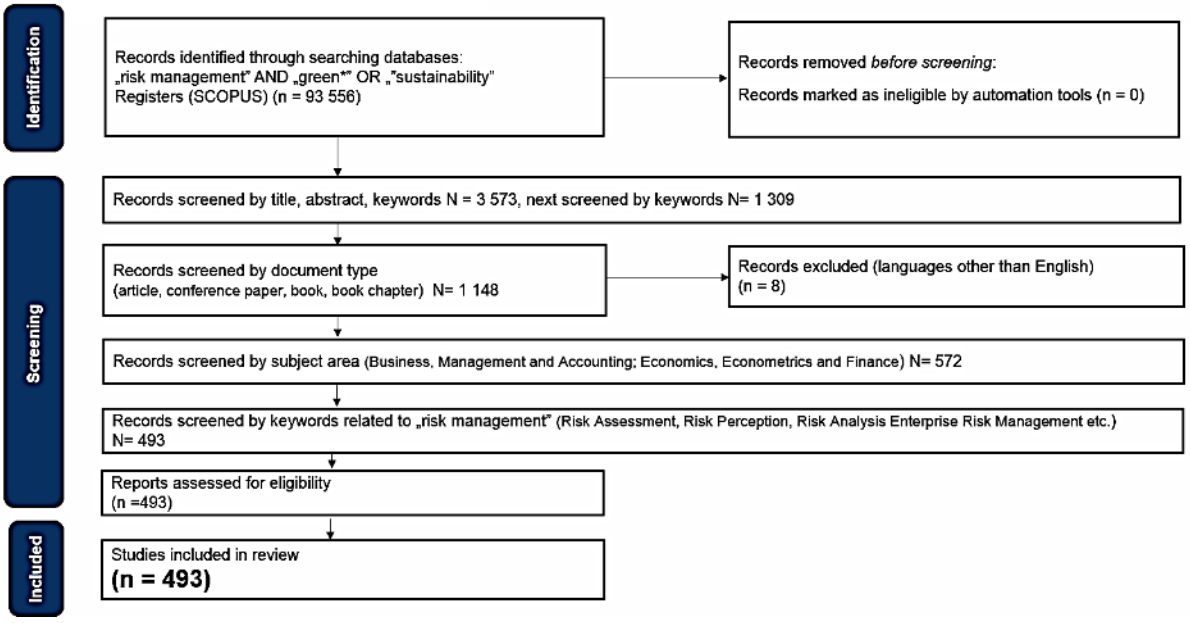

Figure 1. Mapping green risk management constructs - the PRISMA flow diagram.
Source: own elaboration.

As a first step, a bibliometric performance analysis was conducted. The resulting metadata was uploaded to SciMAT and subjected to a bibliometric analysis. This analysis included the calculation of the annual distribution of publications and citations (Figure 2). Figure 2 illustrates the number of papers published annually, with the dashed line indicating the number of citations received. The initial publications addressing risk management within the context of a balanced approach were released in 2004. Thereafter, a gradual increase in the number of publications can be observed. The last five years have seen a surge in both the number of publications and citation trends on this topic. The examination of these trends over the past five years is the subject of further detailed analyses.

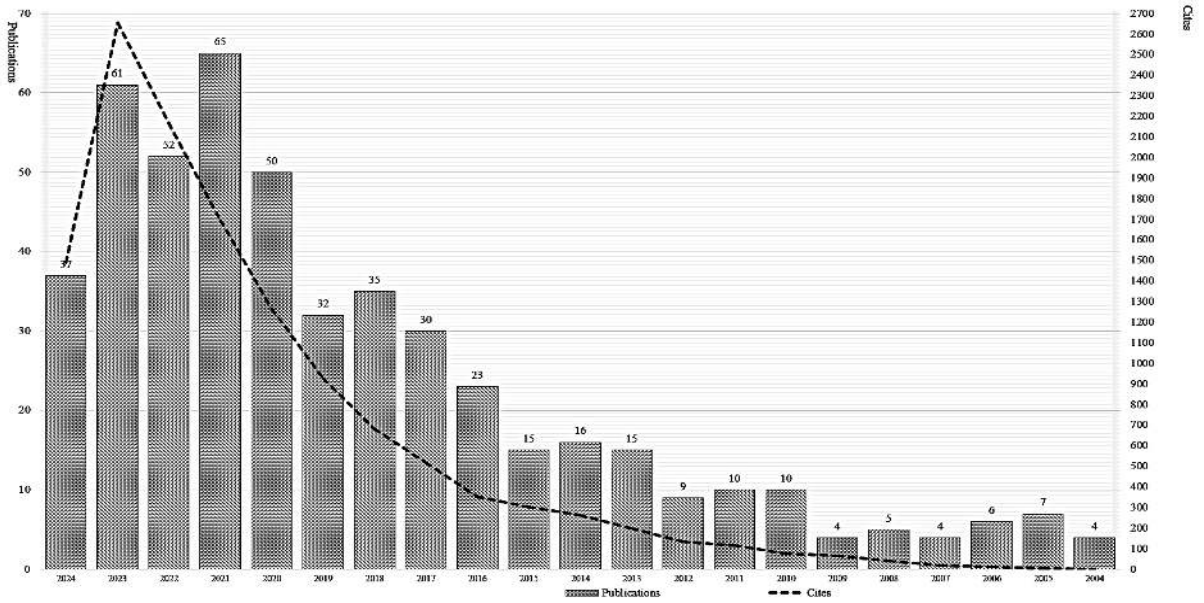

Figure 2. Mapping green risk management constructs - distribution of publication and citations by year. Source: own elaboration.

Table 1 indicates the ten most-cited papers related to different aspects of risk management in the context of a sustainable approach. Despite the earlier indication that the first papers in the selected set of publications date back to 2024, four of the ten most-cited papers are from the last five years, including the publication with the highest total number of citations and the highest citation index per year. The paper most frequently cited by Škare, Soriano and Porada-Rochoń (2021) analyses the impact of the Covid-19 pandemic on the tourism sector, identifying a number of key aspects that shape the current tourism landscape. The article highlights the necessity for the tourism sector to adapt to a new reality in which technological innovation and sustainability are becoming pivotal factors. In the context of a pandemic, the authors propose that tourism models must incorporate social responsibility and long-term sustainability in order to attract tourists in the future (Abbas et al., 2021). It is notable that a significant proportion of the most frequently cited papers (up to four out of ten) address the topic of sustainable risk management in the context of supply chain issues. The study conducted by Giannakis and Papadopoulos (2016) offers significant insights into the function of risk management in the context of supply chain sustainability. Furthermore, the authors contend that effective sustainability risk management is crucial for long-term success and operational efficiency in today's complex business environment. In this regard, they corroborate and extend the conclusions previously established by Govindan et al. (2014), who underscored the significance of integrating sustainability practices into operational strategies and collaborating with stakeholders to attain long-term benefits for both companies and the environment. The most frequently cited studies on the topic of supply chain management in the context of sustainable risk management employed the TOPSIS-CRITIC approach (Abdel-Basset, Mohamed 2020; Rostamzadeh et al., 2018). Other papers have conducted analyses of sustainable risk management in relation to the challenges of transformational processes in sustainable

production: (Pusavec et al., 2010), Industry 4.0 (Birkel et al., 2019), oil and gas pipelines (Shahriar et al., 2012) and smart cities governance (Ullah et al., 2021).

Table 1.
Mapping green risk management constructs – top 10 of the most cited papers

General rank (by TC)	TITLE OF THE PAPER	AUTHOR	JOUR.	YEAR	TC	TCY
1	Impact of COVID-19 on the travel and tourism industry	Škare, M., Soriano, D.R., Porada-Rochoń, M.	TFSC	2021	488	122
2	Supply chain sustainability: A risk management approach	Giannakis, M., Papadopoulos, T.	IJPE	2016	487	60,9
3	Transitioning to sustainable production - Part I: application on machining technologies	Pusavec, F., Krajnik, P., Kopac, J.	JCP	2010	419	32,2
4	Evaluation of sustainable supply chain risk management using an integrated fuzzy TOPSIS-CRITIC approach	Rostamzadeh, R., Ghorabaee, M.K., Govindan, K., Esmaeili, A., Nobar, H.B.K.	JCP	2018	298	59,6
5	Development of a risk framework for Industry 4.0 in the context of sustainability for established manufacturers	Birkel, H.S., Veile, J.W., Müller, J.M., Hartmann, E., Voigt, K.I.	S	2019	282	70,5
6	A methodology to identify sustainability indicators in construction project management - Application to infrastructure projects in Spain	Fernández-Sánchez, G., Rodríguez-López, F.	EI	2010	275	21,2
7	Risk analysis for oil & gas pipelines: A sustainability assessment approach using fuzzy based bow-tie analysis	Shahriar, A., Sadiq, R., Tesfamariam, S.	JLPPI	2012	265	24,1
8	Impact of supply chain management practices on sustainability	Govindan, K., Azevedo, S.G., Carvalho, H., Cruz-Machado, V.	JCP	2014	249	27,7
9	A novel plithogenic TOPSIS- CRITIC model for sustainable supply chain risk management	Abdel-Basset, M., Mohamed, R.	JCP	2020	237	79,0
10	Risk management in sustainable smart cities governance: A TOE framework	Ullah, F., Qayyum, S., Thaheem, M.J., Al-Turjman, F., Sepasgozar, S.M.	TFSC	2021	169	56,3

Abbreviations: JOUR. = Journal; TC = Total citations; TCY = Total citations per year; TFSC = Technological Forecasting and Social Change; CG_IR = International Journal of Production Economics; JCP = Journal of Cleaner Production; EI = Ecological Indicators; S = Sustainability; JLPPI = Journal of Loss Prevention in the Process Industries.

Source: own elaboration.

Furthermore, it is noteworthy that four of the most frequently cited papers on this topic were published in the Journal of Cleaner Production. This is corroborated by a list of the top 10 journals that adopt a sustainable (green) approach to risk management (Table 2). The most frequently published articles in the area were those appearing in Sustainability journal. Of these journals, half are indexed in the ABS journal quality ranking. An analysis of the impact and citation rates of the journals provides confirmation of the quality of the research on this topic. Six out of the ten journals have a Journal Impact Factor greater than ten, while eight out of the ten journals have a Citescore greater than ten, which undoubtedly confirms that a sustainable approach to risk management is currently one of the major research trends in recognized journals.

Table 2.
Mapping green risk management constructs – Top 10 of the most influential journals

Rank	Journal	Document counts	Percentage	Journal Impact Factor™ *	CiteScore*	ABS Ranking **
1	Sustainability (Switzerland)	81	**16,43**	3,9	6,8	n/a
2	Journal of Cleaner Production	27	5,46	11,1	20,4	**2**
3	Environmental Science And Policy	12	2,43	6,0	10,9	**3**
4	Ecological Indicators	12	2,43	6,9	11,8	n/a
5	Resources Policy	9	1,82	10,2	13,4	**2**
6	Business Strategy and the Environment	8	1,62	13,4	22,5	**3**
7	Technological Forecasting and Social Change	7	1,41	12,0	21,3	**3**
8	Water Switzerland	6	1,21	3,4	5,8	n/a
9	Sustainable Cities and Society	6	1,21	11,7	22,0	n/a
10	Resources, Conservation and Recycling	6	1,21	22,9	13,2	n/a

Note: * - 2023 year; ** - 2022; *** - SCOPUS database.

Source: own elaboration.

The following section presents the results of a scientific mapping analysis conducted using the SciMAT software. This analysis identifies the thematic structure and evolution of risk management research that incorporates a sustainable (green) approach over the last five years.

The principal strands of research in each year are discussed in order to illustrate the nature of each of the main themes and sub-themes. The main themes have been identified from the analysis of the strategy diagrams (left side of figures 3-10) while the sub-themes have been identified from the thematic network analysis of the main themes (right side of figures 3-10). The latter provide additional insight into the development of the main themes. Furthermore, as the objective of this article is to examine the latest trends and potentialities in research, the indications of quadrants III and IV in the strategy diagrams are described in detail. Quadrant III (the bottom-left quadrant of the strategy diagram) indicates underdeveloped themes of marginal importance (low density and low centrality according to Cobo et al., 2012) for the research domain. This may indicate the emergence or decline of themes. Quadrant IV (bottom-right quadrant of the strategy diagram) indicates underdeveloped themes of high importance (low density and high centrality according to Cobo et al., 2012) for the research domain. These may be cross-cutting themes that are relevant to the research field but have yet to be fully explored.

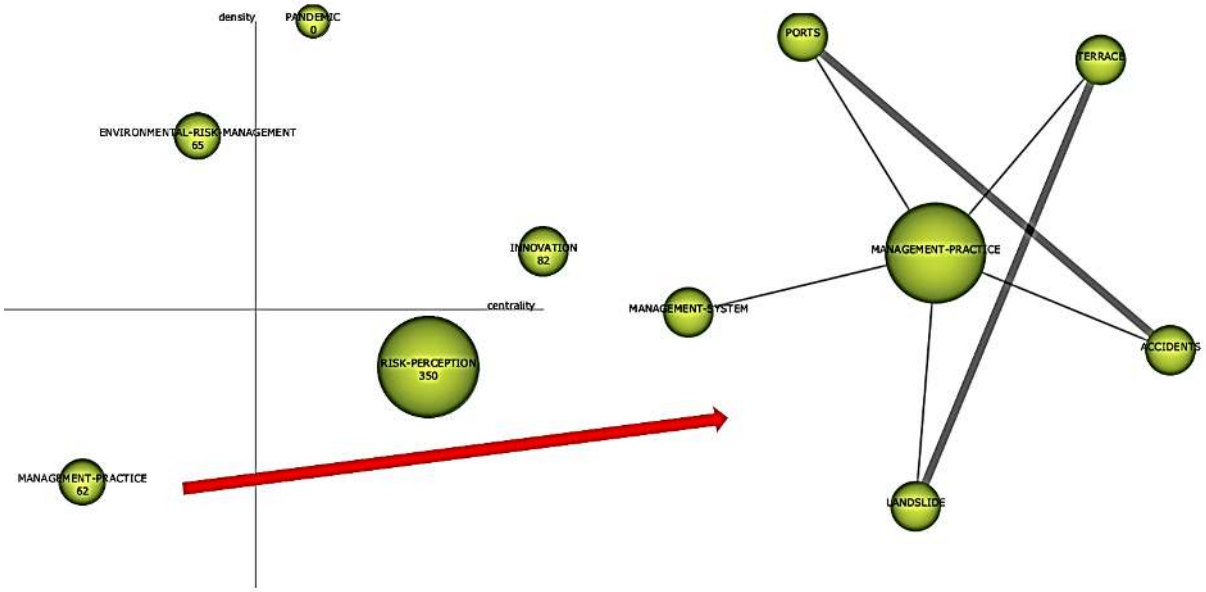

Figure 3. Mapping green risk management constructs - strategic chart (left) and thematic network (right) - 2020 quadrant 3.

Source: own elaboration.

An analysis of Figure 3 shows that research analysing management practices was relevant to the development of research on risk management in the context of a green approach. Work from this period demonstrates the importance of integrating risk management and sustainability in a variety of business areas (Addison et al., 2020; Kadir et al., 2020). The implementation of risk management frameworks and sustainability indicators is key to achieving results that are consistent with responsible development and environmental protection, which are central to modern governance.

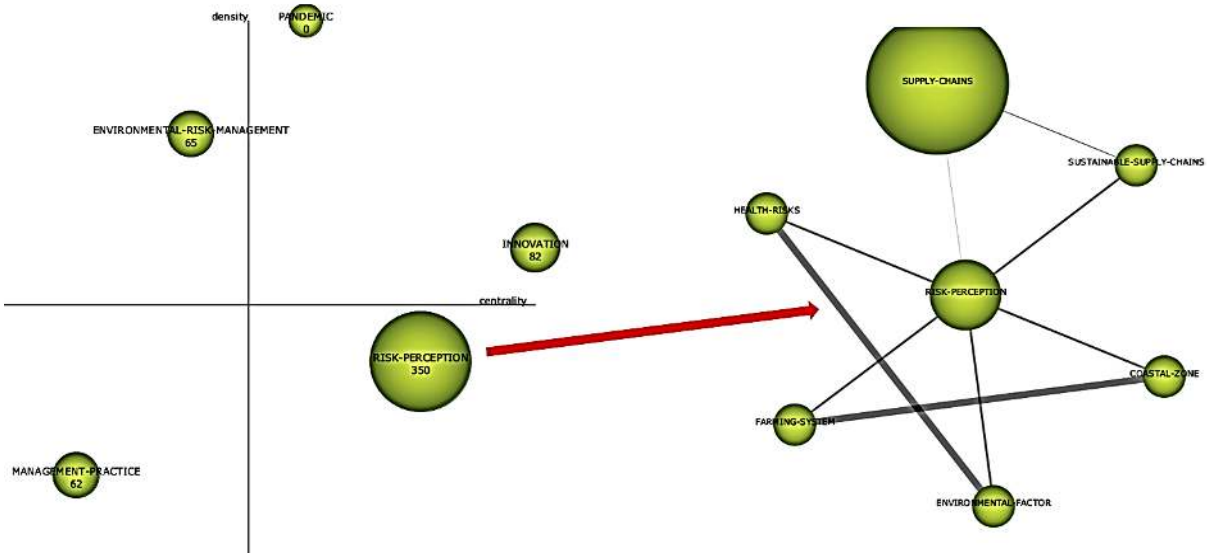

Figure 4. Mapping green risk management constructs - strategic chart (left) and thematic network (right) - 2020 quadrant 4.

Source: own elaboration.

The analysis of figure 4 indicates an emerging theme regarding risk perception. Abdel-Basset and Mohamed (2020), presenting a new model for risk management, pointed out the key role of participants' risk perception, which can vary according to their positions and roles. Adopting this approach allows risk management activities to be aligned with participants' actual concerns and perceived risks, which can improve their effectiveness. This is supported by research by Hallikas, Lintukangas and Kähkönen (2020), who showed that sustainability practices can influence the perception of risk within companies, contributing to a more informed approach to risks associated with supply uncertainty and environmental hazards. Sustainability can shape an organisational culture in which risk is seen as an integral part of strategy, rather than simply a threat to be eliminated.

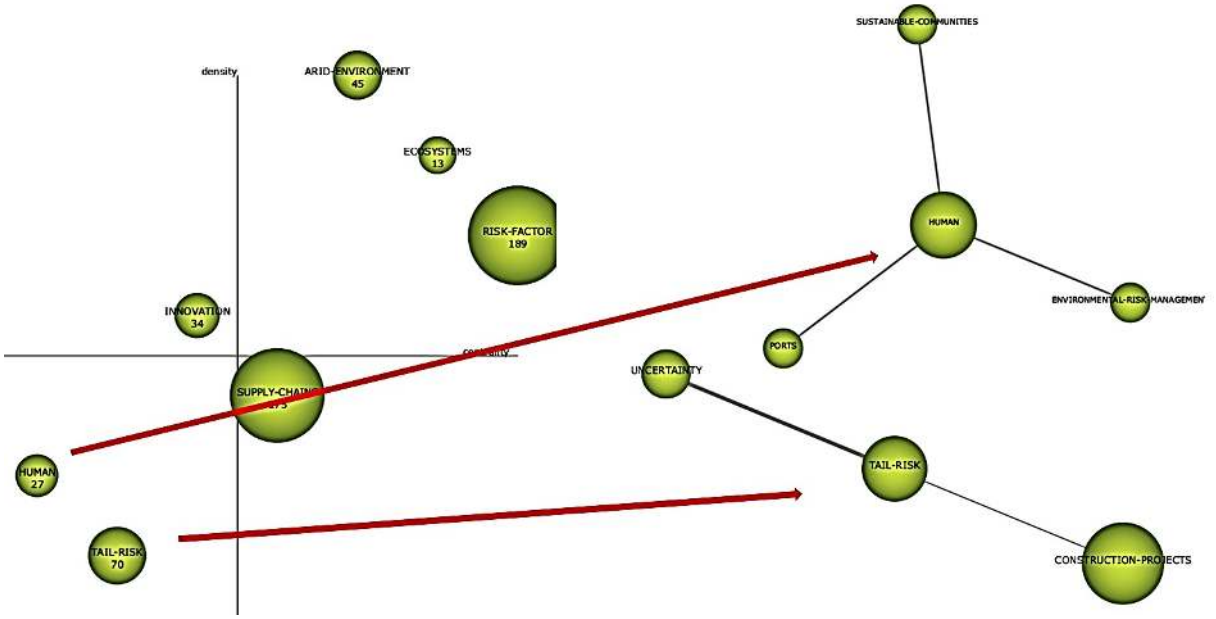

Figure 5. Mapping green risk management constructs - strategic chart (left) and thematic network (right) – 2021 quadrant 3.

Source: own elaboration.

An analysis of Figure 5 shows that research on tail risk analysis and human aspects has been relevant to the development of risk management research in the context of a green approach. Work from this period highlights the importance of tail risk management as a key element in several areas: sustainable construction and public finance (Qazi et al., 2021; Zenios et al., 2021). In the context of construction projects, tail risk management helps to better prepare for unexpected, extreme events that can affect the success and sustainability of a project. In public debt financing, identifying and managing tail risks enables sustainable debt management, which contributes to economic stability and the protection of public interests.

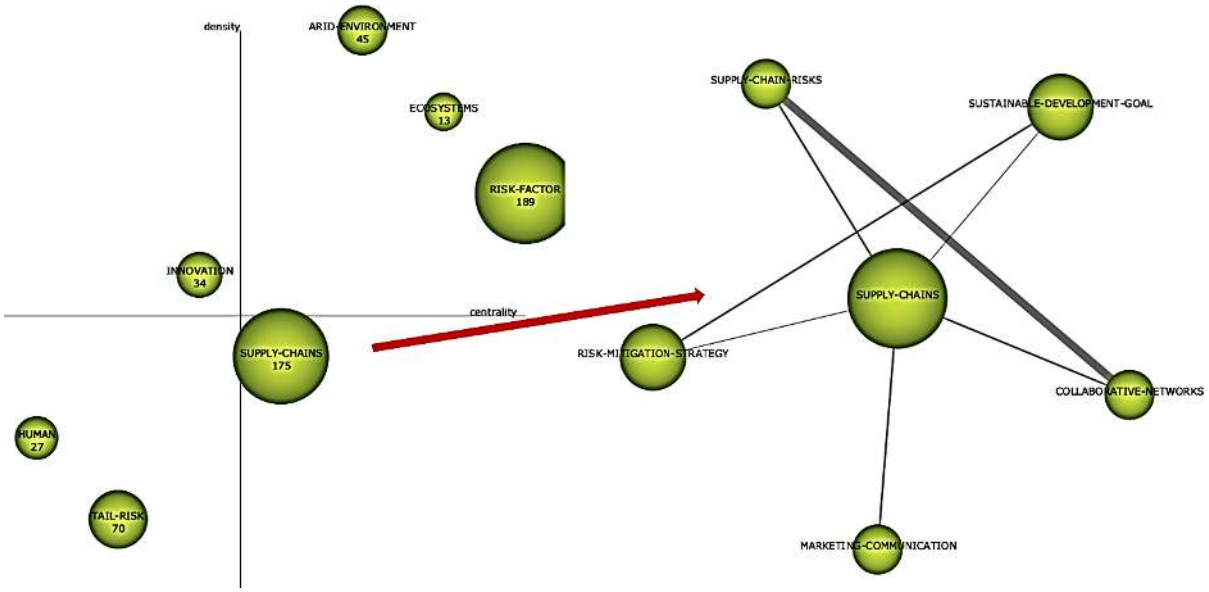

Figure 6. Mapping green risk management constructs - strategic chart (left) and thematic network (right) – 2021 quadrant 4.

Source: own elaboration.

An analysis of Figure 6 shows that there has been mainstream research in the area of risk management in the context of a green approach, with research on supply chain issues. Work from this period emphasises the need for supply chains to evolve towards more sustainable, resilient and technology-based solutions to meet the challenges of modern markets (Fan et al., 2021; Kumar et al., 2021).

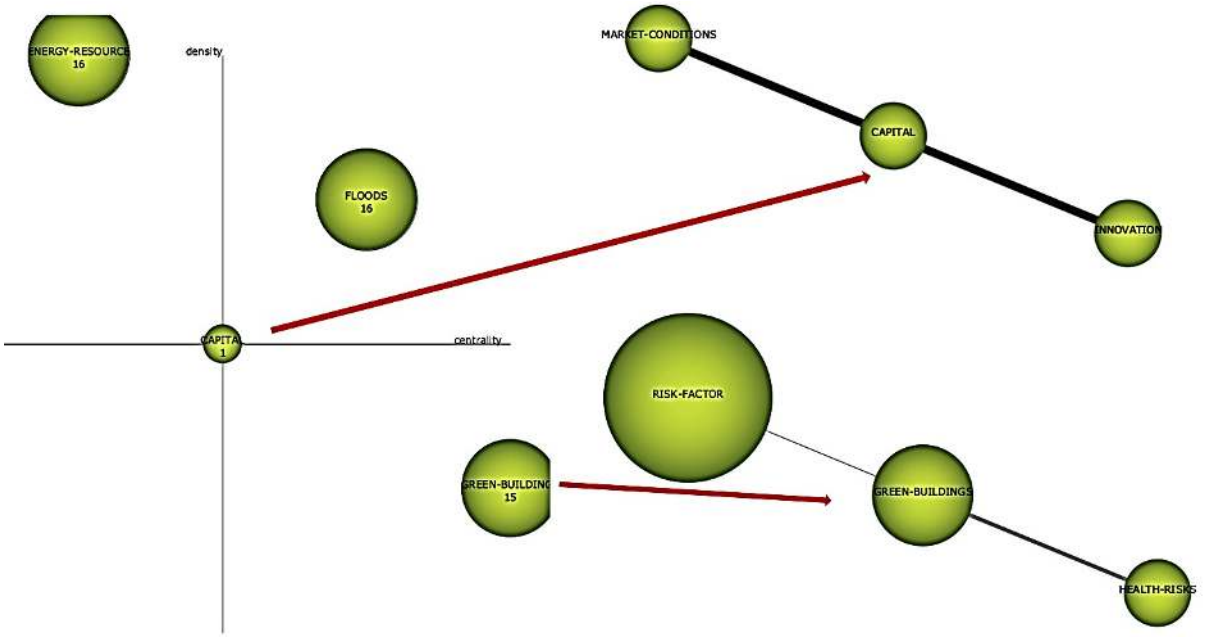

Figure 7. Mapping green risk management constructs - strategic chart (left) and thematic network (right) – 2022 quadrant 4

Source: own elaboration.

An analysis of Figure 7 shows that there has been mainstream research on green building issues in the context of risk management. Work from this period points to different aspects and challenges that are central to green risk management. In the context of sustainable construction, effective risk management means adapting assessment tools, removing financial and technological barriers, and building a stable legal and educational framework (Nguyen, Macchion, 2022; Błach, Klimontowicz, 2021). Such a multi-faceted risk management strategy is essential for the successful implementation of green building projects, especially in resource-constrained environments and emerging markets.

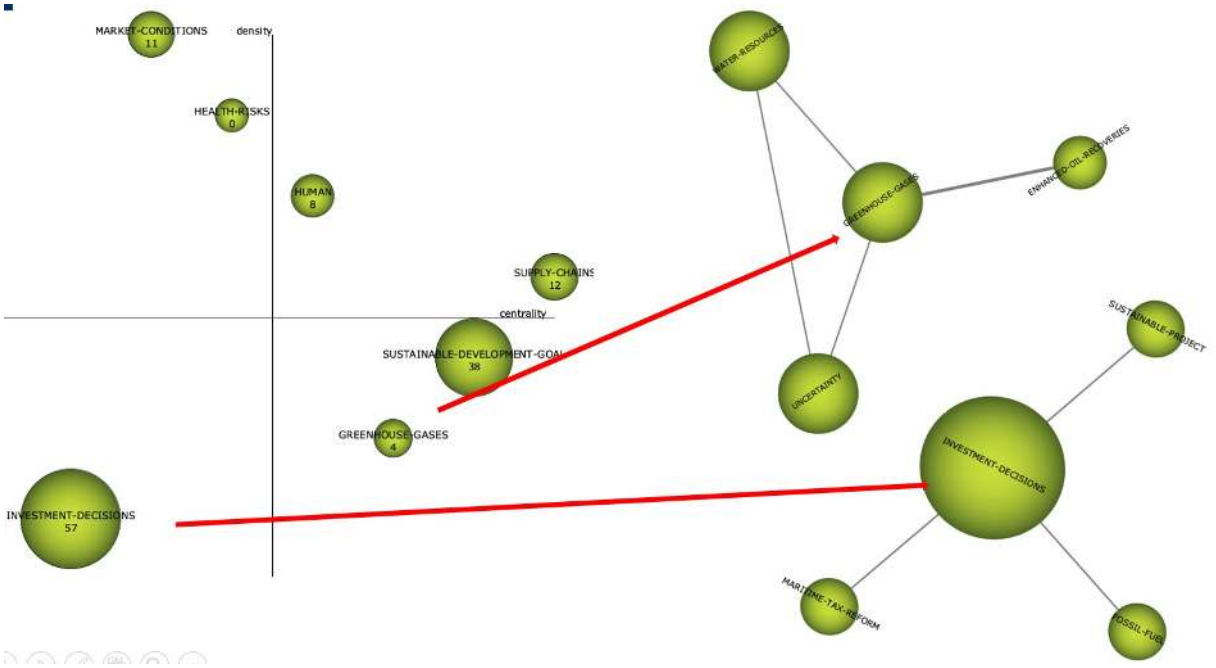

Figure 8. Mapping green risk management constructs - strategic chart (left) and thematic network (right) – 2023 quadrant 3 and 4.

Source: own elaboration.

The analysis of Figure 8 shows that research on risk management in sustainability investing has developed over the next period. They confirm that the integration of ESG factors is crucial for sound investment decisions, pointing in particular to the role of risks arising from the lack of technological synergies and ESG management, the instability of subsidy and incentive policies, the lack of standards and risk assessments of green finance (Alkaraan et al., 2023; Algarvio, 2023). Thus, they suggest that the key challenge in green risk management remains the creation of stable, predictable policy and regulatory frameworks, the implementation of which will minimize the risks associated with sustainability investments.

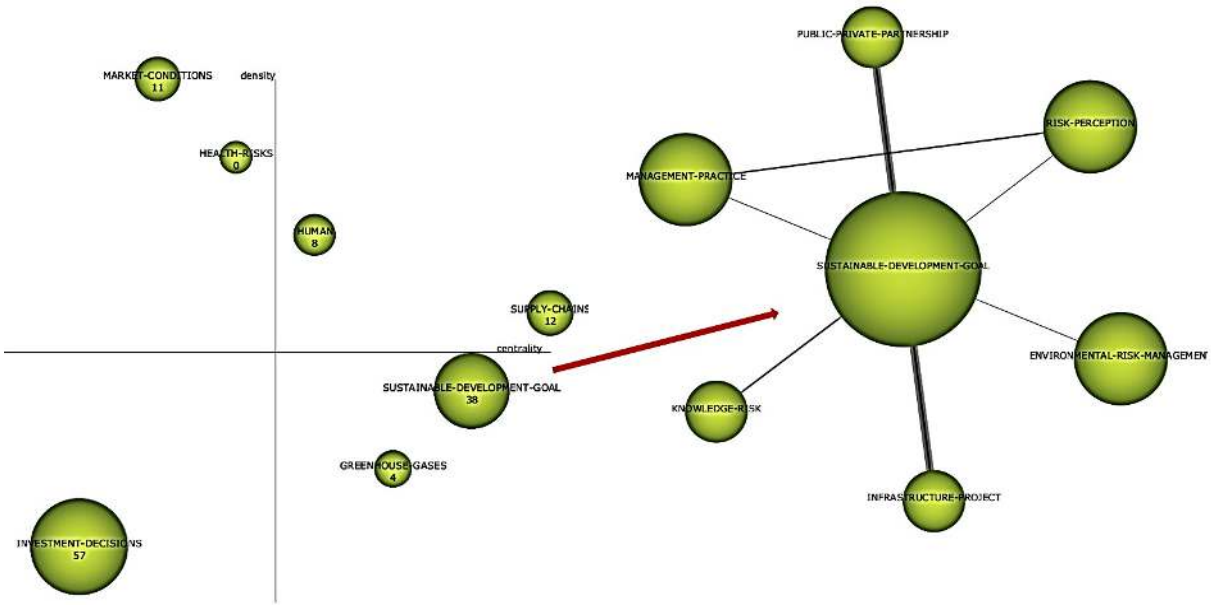

Figure 9. Mapping green risk management constructs - strategic chart (left) and thematic network (right) – 2023 quadrant 4.

Source: own elaboration.

The analysis of figure 9 shows that the research on risk management developed in the subsequent period points to the need for an integrated approach to risk management, taking into account the complexity and the need for clear regulation and access to resources, a holistic approach, transparency of information, while looking critically at the SDG indicators (Akomea-Frimpong et al., 2023; Eckert, Giacona, 2023; Lyytimäki et al., 2023). Research from this period highlights the importance of comprehensive risk management, taking into account environmental, social and information risks, which is crucial for effective green risk management.

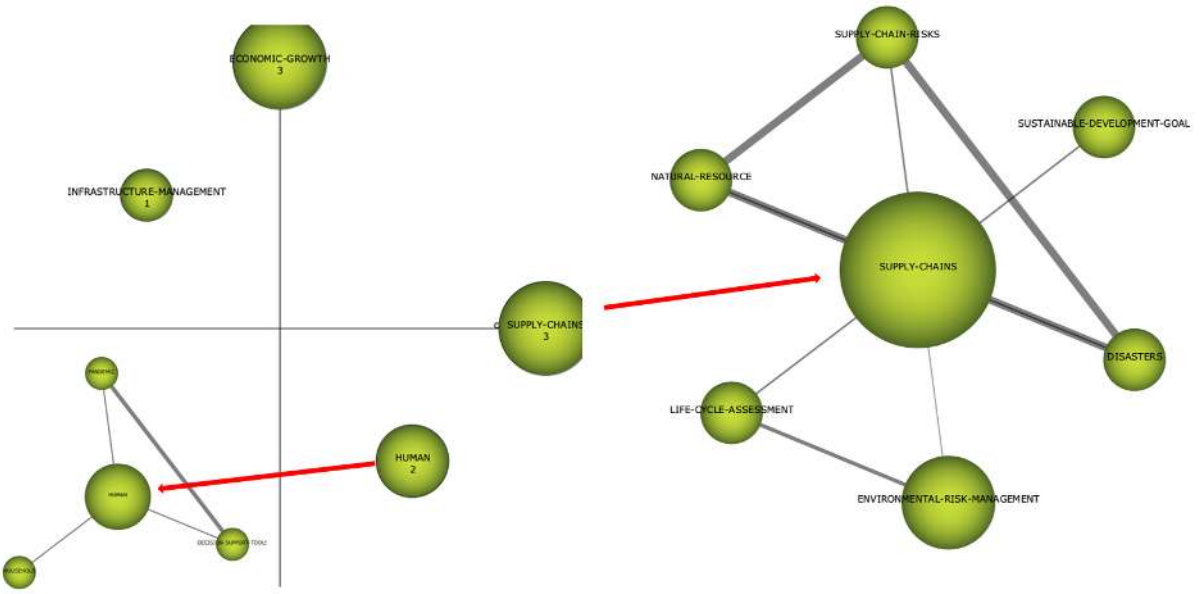

Figure 10. Mapping green risk management constructs - strategic chart (left) and thematic network (right) – 2024 quadrant 4.

Source: own elaboration.

Analysis of Figure 10 shows that recent research on supply chain issues has continued and research on intellectual capital issues has developed. Recent research makes important contributions to the development of green risk management, including the need to automate supplier risk assessment (Chiu et al., 2024), the role of education and CSR as a tool in green risk management and the role of intellectual capital as a basis for building risk resilience (Nazir et al., 2024). Studies continue to support an integrated approach to risk management (Scolobig et al., 2024) as relevant to understanding the interconnectedness of different types of risk and the importance of collaboration and data sharing.

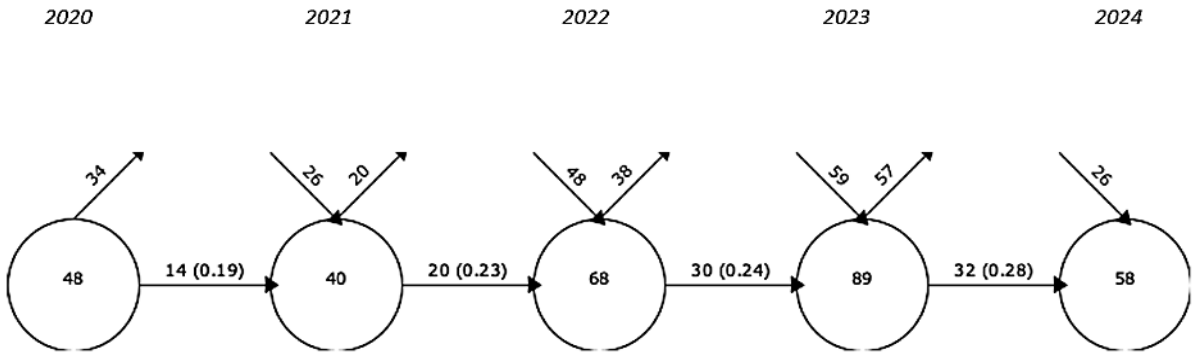

Figure 11. Mapping green risk management constructs - the overlay graph (2020-2024).
Source: own elaboration.

The next step was to analyse the data presented in the overlay graph (Fig. 11). It shows the number of keywords entering and leaving each period (arrows to and around the circles), the number of keywords for consecutive periods (number inside the circle) and, above all, the value of the stability coefficient, which indicates the level of development of the study area. A value of this coefficient close to 1 indicates the maturity of the studied area. The value of the coefficient for green risk management research is currently 0.28, indicating a relatively early stage of development of this research, which is relatively dispersed and lacks established theoretical input. At the same time, the value of the stability index indicates that this is an under-recognised area and therefore one in which researchers may find many research gaps.

The final step in this analysis of green risk management research is to present the identified research trends (discussed in detail earlier in this analysis) together in an evolutionary map (fig. 12). This allows the links between the different areas to be traced over the period analysed.

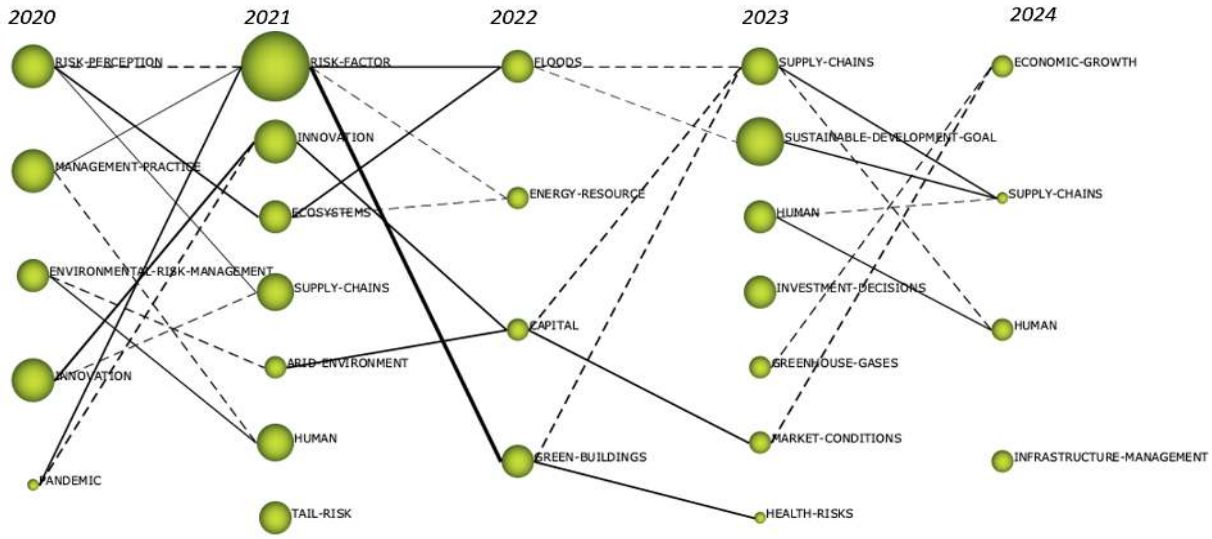

Figure 12. Mapping green risk management constructs - the thematic evolution (2020-2024).
Source: own elaboration.

4. Discussion

This analysis fills an important research gap by identifying dominant, emerging and evolving themes in environmental risk management. In doing so, it helps to place the research discussed in other articles in the context of evolving scientific and practical trends, highlighting the need to integrate technology, intellectual capital, stakeholder engagement and holistic and cross-sectoral approaches in modern environmental risk management practices. This study contributes to a deeper understanding of the evolution of green risk management using analytical tools. In line with research by Moral-Muñoz et al. (2020), among others, the analysis carried out confirms that advanced bibliometric analysis tools make it possible not only to identify major trends, but also to follow the development of key thematic threads. Furthermore, it confirms the relevance of research on risk management in sustainable supply chains, especially in the context of the integration of social and environmental risks in companies' operational strategies and the complexity of modern supply chains (Giannakis, Papadopoulos, 2016; Cui et al., 2024). This research highlights the importance of social aspects and stakeholder engagement as an indispensable component of the effectiveness of companies' green risk management efforts. This perspective can be found, among others, in the work of Freise and Seuring (2015), who highlight the importance of managing stakeholder expectations and their impact on the achievement of a company's environmental and social goals as an approach to reducing reputational risk and increasing transparency of operations. The study shows a low stability coefficient for green risk management (0.28), indicating that the field is still at an early stage of development. This is in line with a study by Martins et al. (2022),

which examines the maturity of different research disciplines, noting the lack of consolidation and high dynamics of change in emerging fields, suggesting ample opportunities for future research in this area. The study highlights that the sustainable approach to risk management is evolving towards a holistic, multi-faceted approach that considers environmental, social and financial risks. These findings are consistent with the work of Billio et al. (2024), who point to the importance of including sustainable risks in credit assessments in the context of transparency and financial accountability of organisations, which determine their long-term sustainability.

In summary, the paper is a valuable development of the existing literature and points to areas for further academic exploration in the field of sustainable risk management.

5. Summary

The study analyses the development of research on green risk management, an approach that integrates environmental and social considerations into a traditional risk management framework. The paper focuses on the identification and development of key research themes and the recognition of their relevance to business and financial practice. The analysis was based on 493 articles from the Scopus database published in the last five years. The SciMAT tool was used, which allows thematic analysis over time and shows the evolution of the research field in the context of green risk management.

Key findings from the analysis include several areas:

1. Increased interest and development of research

   There has been a gradual increase in the number of publications on green risk management since 2004, but there has been a significant increase in both the number of publications and citations over the last five years, indicating the growing importance of the topic. The analysis shows that there has been a particular focus on risk management related to supply chains, sustainable construction, ESG (environmental, social and governance) investment and financial risk management in the public sector.

2. Main and sub-thames

   The analysis identified a variety of main and sub-themes, such as supply chain risk management, green building, sustainable investment management, risk perception and the role of intellectual capital. The SciMAT software used made it possible to track changes over time by classifying themes into main and sub-themes and assessing their relevance. Among other things, it showed that the early stages of the research (2004-2019) were dominated by themes related to risk in sustainable supply chains, which later evolved to include areas such as ESG-related investment risk and intellectual issues in risk management.

3. Research is at a relatively early stage of development
   Research is scattered and the theoretical underpinnings are not well established, suggesting that there are significant research gaps and scope for further research into the underlying constructs of the topic.
4. Identifying and developing key trends
   The issues of risk in green building and risk management in ESG investment have received particular attention in recent years. The findings suggest that the challenge remains to create a stable policy and regulatory framework to effectively support risk management in these areas. The research points to the need for an automated supplier risk assessment system and the growing importance of environmental education and CSR as elements to support long-term sustainability. It also highlights the role of intellectual capital in increasing companies' resilience to risk and supporting a culture of sustainability.

6. Potential for further research

The research suggests that despite growing interest, green risk management remains an area in need of more established theories and research approaches, particularly in terms of research systematisation and conceptual integration with other disciplines. Further research is needed that could focus on the development of robust tools and models, and the integration of environmental and social approaches into risk management.

The paper highlights the critical importance of integrating environmental and social aspects into risk management, indicating that green risk management is evolving towards more complex and integrated approaches. The analysis suggests that companies need to adapt to new market and regulatory requirements, leading to an increasing emphasis on proactive approaches to risk management in areas such as construction, supply chains, finance and ESG.

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References

1. Abbas, J., Mubeen, R., Iorember, P.T., Raza, S., Mamirkulova, G. (2021). Exploring the impact of covid-19 on tourism: transformational potential and implications for a sustainable recovery of the travel and leisure industry. *Current Research in Behavioral Sciences, 2, 100033*. Retrieved from: https://doi.org/10.1016/j.crbeha.2021.100033.
2. Abdel-Basset, M., Mohamed, R. (2020). A novel plithogenic TOPSIS-CRITIC model for sustainable supply chain risk management. *Journal of Cleaner Production, 247*, *119586*.
3. Abdel-Basset, M., Mohamed, R. (2020). A novel plithogenic TOPSIS-CRITIC model for sustainable supply chain risk management. *Journal of Cleaner Production, 247, 119586*.
4. Addison, P.F., Stephenson, P.J., Bull, J.W., Carbone, G., Burgman, M., Burgass, M.J., Milner-Gulland, E.J. (2020). Bringing sustainability to life: A framework to guide biodiversity indicator development for business performance management. *Business Strategy and the Environment, 29(8),* pp. 3303-3313.
5. Akomea-Frimpong, I., Jin, X., Osei-Kyei, R., Kukah, A.S. (2023). Public–private partnerships for sustainable infrastructure development in Ghana: a systematic review and recommendations. *Smart and Sustainable Built Environment, 12(2),* pp. 237-257.
6. Algarvio, H. (2023). The Economic Sustainability of Variable Renewable Energy Considering the Negotiation of Different Support Schemes. *Sustainability, 15(5), 4471.*
7. Alkaraan, F., Elmarzouky, M., Hussainey, K., Venkatesh, V.G. (2023). Sustainable strategic investment decision-making practices in UK companies: The influence of governance mechanisms on synergy between industry 4.0 and circular economy. *Technological Forecasting and Social Change, 187, 122187.*
8. Aziz, N., Manab, N., Othman, S. (2016). Sustainability risk management (srm): an extension of enterprise risk management (erm) concept. *International Journal of Management and Sustainability, 5(1), 1-10*. Retrieved from: https://doi.org/10.18488/ journal.11/ 2016.5.1/11.1.1.10.
9. Bakhtawar, B., Thaheem, M., Arshad, H., Tariq, S., Mazher, K., Zayed, T., Akhtar, N. (2021). A sustainability-based risk assessment for p3 projects using a simulation approach. *Sustainability, 14(1), 344*. Retrieved from: https://doi.org/10.3390/su14010344.
10. Billio, M., Costola, M., Hristova, I., Latino, C., Pelizzon, L. (2024). Sustainable finance: A journey toward ESG and climate risk. *International Review of Environmental and Resource Economics, 18(1-2).*
11. Birkel, H.S., Veile, J.W., Müller, J.M., Hartmann, E., Voigt, K.I. (2019). Development of a risk framework for Industry 4.0 in the context of sustainability for established manufacturers. *Sustainability*, *11*(2), *384.*

12. Błach, J., Klimontowicz, M. (2021). The Determinants of PayTech's success in the mobile payment market—the case of BLIK. *Journal of Risk and Financial Management, 14(9), 422.*
13. Chiu, M.C., Tai, P.Y., Chu, C.Y. (2024). Developing a smart green supplier risk assessment system integrating natural language processing and life cycle assessment based on AHP framework: An empirical study. *Resources, Conservation and Recycling, 207, 107671.*
14. Cobo, M.J., López-Herrera, A.G., Liu, X., Herrera, F. (2012). Scimat: a new science mapping analysis software tool. *Journal of the American Society for Information Science and Technology, 63(8),* pp. 1609-1630. Retrieved from: https://doi.org/10.1002/asi.22688.
15. Cobo, M.J., López-Herrera, A.G., Liu, X., Herrera, F. (2011). Science mapping software tools: review, analysis, and cooperative study among tools. *Journal of the American Society for Information Science and Technology, 62(7),* pp. 1382-1402. Retrieved from: https://doi.org/10.1002/asi.21525
16. Cui, Z., Lu, S., Liu, J. (2024). Research on risk management incentive strategy based on the green financial ecosystem. *Plos One, 19(4), e0300629*.
17. Dobler, M., Lajili, K., Zéghal, D. (2012). Environmental performance, environmental risk and risk management. *Business Strategy and the Environment, 23(1),* pp. 1-17. Retrieved from: https://doi.org/10.1002/bse.1754.
18. Eckert, N., Giacona, F. (2023). Towards a holistic paradigm for long-term snow avalanche risk assessment and mitigation. *Ambio, 52(4),* pp. 711-732.
19. Eller, M., Beck, J., Hedrich, M., Urban, W. (2016). A new sustainability controlling approach for urban water systems: multidimensional risk identification and system analysis. *Journal of Environmental Science and Engineering - A, 5(8).* Retrieved from: https://doi.org/10.17265/2162-5298/2016.08.005
20. Fan, D., Xiao, C., Zhang, X., Guo, Y. (2021). Gaining customer satisfaction through sustainable supplier development: The role of firm reputation and marketing communication. *Transportation Research Part E: Logistics and Transportation Review, 154, 102453.*
21. Freise, M., Seuring, S. (2015). Social and environmental risk management in supply chains: a survey in the clothing industry. *Logistics Research, 8(1).* Retrieved from: https://doi.org/10.1007/s12159-015-0121-8.
22. Freise, M., Seuring, S. (2015). Social and environmental risk management in supply chains: a survey in the clothing industry. *Logistics Research, 8,* pp. 1-12.
23. Giannakis, M., Papadopoulos, T. (2016). Supply chain sustainability: A risk management approach. *International Journal of Production Economics, 171,* pp. 455-470.
24. Gomez-Valencia, M., González-Pérez, M., Gómez-Trujillo, A. (2021). The "six ws" of sustainable development risks. *Business Strategy and the Environment, 30(7),* pp. 3131-3144. Retrieved from: https://doi.org/10.1002/bse.2794.

25. Gonzales-Aguilar, A., Colmenero-Ruiz, M., Paletta, F., Verlaet, L. (2023). Loet leydesdorff: bibliometric analysis and mapping of his scientific production. *El Profesional De La Información*. Retrieved from: https://doi.org/10.3145/epi.2023.dic.09.
26. Gorzeń-Mitka, I., Wieczorek-Kosmala, M. (2023). Mapping the energy sector from a risk management research perspective: A bibliometric and scientific approach. *Energies, 16(4), 2024.*
27. Govindan, K., Azevedo, S.G., Carvalho, H., Cruz-Machado, V. (2014). Impact of supply chain management practices on sustainability. *Journal of Cleaner Production, 85,* pp. 212-225.
28. Hallikas, J., Lintukangas, K., Kähkönen, A.K. (2020). The effects of sustainability practices on the performance of risk management and purchasing. *Journal of Cleaner Production, 263, 121579.*
29. Haywood, L. (2021). Putting risk management into the corporate sustainability context. *Social Responsibility Journal, 18(8), 1485-1504*. Retrieved from: https://doi.org/10.1108/ srj-06-2019-0201.
30. Hofmann, H., Busse, C., Bode, C., Henke, M. (2013). Sustainability-related supply chain risks: conceptualization and management. *Business Strategy and the Environment, 23(3), 160-172*. Retrieved from: https://doi.org/10.1002/bse.1778.
31. Iliescu, A.N. (2024). Green Knowledge Management—Bibliometric Analysis. *Encyclopedia, 4(2),* pp. 923-935.
32. Kadir, A.Z., Mohammad, R., Othman, N., Amrin, A., Muhtazaruddin, M.N., Abu-Bakar, S.H., Muhammad-Sukki, F. (2020). Risk management framework for handling and storage of cargo at major ports in Malaysia towards port sustainability. *Sustainability, 12(2), 516.*
33. Krysiak, F. (2009). Risk management as a tool for sustainability. *Journal of Business Ethics, 85(S3),* pp. 483-492. Retrieved from: https://doi.org/10.1007/s10551-009-0217-7.
34. Kumar, A., Mangla, S.K., Kumar, P., Song, M. (2021). Mitigate risks in perishable food supply chains: Learning from COVID-19. *Technological Forecasting and Social Change, 166, 120643.*
35. Lambert, H. (2023). Effects of project risks management and sustainability of manufacturing industry projects in Rwanda - a case study of Sulfo Industries Ltd. *Cognizance Journal of Multidisciplinary Studies, 3(10),* pp. 361-376. Retrieved from: https://doi.org/10.47760/ cognizance.2023.v03i10.024.
36. Lyytimäki, J., Eckert, N., Lepenies, R., Mosoni, C., Mustajoki, J., Pedersen, A.B. (2023). Assuming accuracy, pretending influence? Risks of measuring, monitoring and reporting sustainable development goals. *Ambio, 52(4),* pp. 702-710.
37. Martins, T., Braga, A., Ferreira, M.R., Braga, V. (2022). Diving into social innovation: a bibliometric analysis. *Administrative Sciences, 12(2), 56*. Retrieved from: https://doi.org/10.3390/admsci12020056.

38. Moral-Muñoz, J.A., Herrera-Viedma, E., Santisteban-Espejo, A., Cobo, M.J. (2020). Software tools for conducting bibliometric analysis in science: An up-to-date review. *Profesional de la Información, 29(1).*
39. Nazir, S., Ali, M., Saeed, M., Mubarik, M.S., Jalil, Q. (2024). Sustainable performance and disaster management in the oil and gas industry: An intellectual capital perspective. *Resources Policy, 92, 105042.*
40. Nguyen, H.D., Macchion, L. (2022). Exploring critical risk factors for Green Building projects in developing countries: The case of Vietnam. *Journal of Cleaner Production, 381, 135138.*
41. Page, M.J., McKenzie, J., Bossuyt, P., Boutron, I., Hoffmann, T., Mulrow, C., Moher, D. (2020). *The PRISMA 2020 statement: an updated guideline for reporting systematic reviews*. Retrieved from: https://doi.org/10.31222/osf.io/v7gm2.
42. Pusavec, F., Krajnik, P., Kopac, J. (2010). Transitioning to sustainable production–Part I: application on machining technologies. *Journal of Cleaner Production, 18(2),* pp. 174-184.
43. Qazi, A., Shamayleh, A., El-Sayegh, S., Formaneck, S. (2021). Prioritizing risks in sustainable construction projects using a risk matrix-based Monte Carlo Simulation approach. *Sustainable Cities and Society, 65, 102576.*
44. Rostamzadeh, R., Ghorabaee, M.K., Govindan, K., Esmaeili, A., Nobar, H.B.K. (2018). Evaluation of sustainable supply chain risk management using an integrated fuzzy TOPSIS-CRITIC approach. *Journal of Cleaner Production, 175,* pp. 651-669.
45. Scolobig, A., Santos, M.J., Willemin, R., Kock, R., Battiston, S., Petchey, O., Stoffel, M. (2024). Learning from COVID-19: A roadmap for integrated risk assessment and management across shocks of pandemics, biodiversity loss, and climate change. *Environmental Science & Policy, 155, 103726.*
46. Shahriar, A., Sadiq, R., Tesfamariam, S. (2012). Risk analysis for oil & gas pipelines: A sustainability assessment approach using fuzzy based bow-tie analysis. *Journal of Loss Prevention in the Process Industries, 25(3),* pp. 505-523.
47. Shao, C., Yang, J., Tian, X., Mei, J., Huang, L. (2013). Integrated environmental risk assessment and whole-process management system in chemical industry parks. *International Journal of Environmental Research and Public Health, 10(4),* pp. 1609-1630. Retrieved from: https://doi.org/10.3390/ijerph10041609.
48. Sipa, M., Sitek, M. (2024). Research Trends in Knowledge Management and Innovation: a Bibliometric Review. *In European Conference on Knowledge Management, Vol. 25, No. 1,* pp. 761-770.
49. Škare, M., Soriano, D.R., Porada-Rochoń, M. (2021). Impact of covid-19 on the travel and tourism industry. *Technological Forecasting and Social Change, 163, 120469*. https://doi.org/10.1016/j.techfore.2020.120469.

50. Tomaszewski, R. (2023). Visibility, impact, and applications of bibliometric software tools through citation analysis. *Scientometrics, 128(7),* pp. 4007-4028.
51. Ullah, F., Qayyum, S., Thaheem, M.J., Al-Turjman, F., Sepasgozar, S.M. (2021). Risk management in sustainable smart cities governance: A TOE framework. *Technological Forecasting and Social Change, 167, 120743.*
52. Weber, O. (2011). Environmental credit risk management in banks and financial service institutions. *Business Strategy and the Environment, 21(4),* pp. 248-263. Retrieved from: https://doi.org/10.1002/bse.737.
53. Weber, O., Scholz, R., Michalik, G. (2008). Incorporating sustainability criteria into credit risk management. *Business Strategy and the Environment, 19(1),* pp. 39-50. Retrieved from: https://doi.org/10.1002/bse.636.
54. Xue, B., Zhang, Z., Li, P. (2019). Corporate environmental performance, environmental management and firm risk. *Business Strategy and the Environment, 29(3),* pp. 1074-1096. Retrieved from: https://doi.org/10.1002/bse.2418.
55. Zenios, S.A., Consiglio, A., Athanasopoulou, M., Moshammer, E., Gavilan, A., Erce, A. (2021). Risk management for sustainable sovereign debt financing. *Operations Research, 69(3),* pp. 755-773.

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DETERMINANTS OF ENERGY TRENDS BASED ON RENEWABLE ENERGY SOURCES

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Purpose: The aim of the article is to analyze the energy economy in terms of conditions influencing contemporary energy trends. In particular, new requirements are compared with existing habits and the role of the state in shaping the desired energy trends is indicated. An attempt was also made to indicate how to improve the efficiency of energy management. The role of the local energy market was taken into account.
Design/methodology/approach: The article consists of literature studies, which are a review of publications and legal acts on the energy economy, in particular that based on renewable energy sources. The research allowed us to characterize new energy trends occurring in the economies of many developed countries.
Findings: During the research, an attempt was made to identify the determinants of energy trends, in particular those involving renewable energy sources.
Research limitations/implications: Based on the research conducted, future implications can be identified. They may involve stimulating selected energy trends in such a way that they effectively translate into positive effects for the environment.
Practical implications: The practical implications of the obtained results may concern the further use by decision-makers of appropriate instruments that, introduced into the economy, would stimulate the development of renewable energy sources.
Originality/value: The article compares energy trends observed in various developed countries. The value of such research is the ability to stimulate positive environmental effects through the use of appropriate tools to stimulate the development of renewable energy sources.
Keywords: energy economy, energy crisis, renewable energy.
Category of the paper: Research paper.

1. Introduction

The number of inhabitants on our planet is increasing very quickly. In 1800, the planet had 1 billion inhabitants. In 1900, there were already 1.6 billion of us. Population growth was much greater in the next century (Poborski, Kraska, 2023). In 1987, the planet was inhabited by 5 billion people, and in 2024 it will be 8.1 billion (Janicki, 2024). The rapid increase in population combined with economic development and an increase in the standard of living resulted in a sharp increase in energy demand. This resulted in the rapid exploitation of fossil fuels in the form of coal and oil. The burning of fossil fuels has disturbed the biological balance. The amount of carbon dioxide released when burning fossil fuels is too large to be absorbed by the plant world. The area of forests, especially tropical ones, is rapidly decreasing, and the cleared areas are being developed for development.

Disturbance of biological balance has led to drastic and dangerous climate changes. Immediate changes to energy policy are required to restore biological balance.

2. New requirements for energy management

The current energy situation requires immediate changes in the field of energy management. Changes in energy management must be taken into account:

- improving the energy efficiency of devices - improving energy efficiency is the most economically effective method of reducing energy demand (Dołęga, 2022; Sochacki, 2023);
- implementation of renewable energy sources at the user level - photovoltaic energy, wind energy, geothermal energy, solar thermal energy, etc. - these are very expensive projects (Wojciechowska, 2021);
- decentralization of the energy market and creation of local energy markets – selling and buying energy from neighbors using the existing network and an appropriate Internet program enabling energy trading bypassing the energy company. Prices are agreed between the seller and the buyer without the involvement of an intermediary (Bałamut A. et al., 2024; Mól et al., 2022);
- changing old habits - this is the most difficult to implement, and the main barrier is people's tendency to expect immediate reward. People's behavior is largely influenced by the behavior of neighbors/social norms. In some environments, positive trends towards the construction of small passive houses that are self-sufficient in terms of energy are already visible. They are more expensive to build, but profitable in the long run;

- installations of "smart" electricity meters that track the current cost of energy - the cost of energy depends on demand. Smart meters can turn individual energy receivers off and on depending on the energy cost (KIGEiT, 2022). The energy consumer programs the smart meter to turn on and off individual receivers depending on the current energy price (turning off the air conditioning, refrigerator or heating for a few hours may not even be noticeable to the user).

3. The role of the state in promoting future-proof solutions

All initiatives related to the implementation of energy-saving devices as well as renewable energy sources are expensive. Passive buildings that are self-sufficient in energy, as well as electric and hybrid vehicles, are also expensive. These investments pay off only after a longer period. In some cases, the payback period is 10 - 20 years. People tend to make decisions based on immediate benefits. The role of the state is to reward investments aimed at promoting renewable energies, as well as reducing energy consumption by increasing the energy efficiency of devices. The most effective method is tax breaks that reward people who make energy-saving investments. One of the most extensive tax relief systems for the clean energy sector is the system in force in the United States. It is referred to as the "Investing in America" program. In the USA, there are currently, among others: the following tax breaks:

- 26% tax relief for the installation of photovoltaic panels, geothermal systems and wind turbines - 26% of the installation costs are deducted from income tax;
- a tax credit of up to $7600 for the purchase of an electric or hybrid car with a battery capacity greater than 5 kWh;
- tax relief for the purchase and installation of an energy-saving heating and air-conditioning system, energy-saving refrigerators, water heaters, washing machines, etc. - the amount of the relief changes annually;
- low-interest loans for the purchase and installation of energy-saving heating and air conditioning systems as well as the construction of passive houses that are self-sufficient in terms of Energy;
- tax credits for energy communities and businesses and state and local governments under the Qualifying Advanced Energy Project Tax Credit program - under selected projects, the entities listed may receive a 30 percent tax credit for clean energy investments.

In the European Union, there are also many tax breaks and subsidies promoting renewable energy sources, as well as increasing energy efficiency to reduce energy consumption. Individual European Union countries take a number of actions to support renewable energy sources (Guidelines..., 2022), create programs for enterprises from the "net-zero" sector,

and support local investments. For example, in 2023 Spain spent EUR 1.1 billion on supporting enterprises in the form of subsidies, France allocated EUR 2.9 billion for this purpose, and Portugal EUR 350 million (List of Member…, 2024). EU Member States, under the Temporary Crisis Framework and Guidelines (Guidelines..., 2022), create, among others: subsidy mechanisms dedicated to investments in green hydrogen, renewable energy and industrial decarbonization. Some of these countries also receive funds from the Cohesion Fund and the Recovery and Resilience Facility. As part of the latter, a total of EUR 18.61 billion in the form of subsidies has so far been paid to EU countries for the purposes of green transformation. Italy, Spain and France received over 70% of this amount (Zawadzka, Hofman, 2024).

The role of the state in promoting future-oriented solutions is very important. Each new technology is initially expensive and requires financial support from the state. The development of new technologies related to the generation of renewable energy as well as the improvement of the energy efficiency of devices stimulates economic development and contributes to the creation of new jobs. Currently, there is a great demand for specialists in various fields related to sustainable development. The energy transformation is associated with the need for green technology specialists, energy efficiency engineers, data analysts using artificial intelligence for forecasting and energy demand management, as well as people responsible for creating smart grids that allow the integration of AI with energy systems. Experts from the World Economic Forum forecast that the green transformation has the potential to create over 10 million new jobs globally this decade. Employment growth will be driven primarily by energy efficiency, which may generate up to 3.2 million jobs. Specialists responsible for applying technologies and practices that enable sustainable development will be extremely desirable on the labor market (https://www.money.pl, 2024).

4. Economy energy intensity index and energy mix

The energy intensity of an economy is measured by the "energy intensity coefficient", which shows the amount of energy involved in economic processes, and in particular the amount of energy needed to produce a given amount of products. The energy intensity index is most often related to GDP. The use of energy carriers in economic processes is of key importance for the sustainable development of the economy. Energy has no substitutes and therefore can determine the rate of economic growth (Peet, 2004). The role of energy in economic processes, and especially as a factor in sustainable development, is constantly growing and is expected to grow even more in the future (Plich, Skrzypek, 2016). This makes striving to ensure energy security a priority of every economy. At the same time, the growing demand for energy has intensified both the global and national discussion on the structure of

energy consumption, ensuring energy security and contributing to limiting the negative effects of energy production and consumption on the natural environment, i.e. the so-called optimal energy mix.

Table 1 contains the energy intensity coefficient of the economy of selected countries (from the most to the least energy intensive), calculated as energy inputs per unit of GDP. Poland is in the middle of the table.

Table 1.
Energy intensity coefficient of the economy of selected countries

Country	Energy Intensity Ratio of the Economy [kWh/dolar]
Iran	11.12
Russia (Russian Federation)	8.10
Ukraine	6.95
United States	4.40
Australia	4.30
Sweden	3.80
Poland	3.42
Norway	3.33
France	3.29
Germany	2.76
Spain	2.64
Great Britain	2.30
Ireland	2.30

Source: own study based on European Commission, Directorate-General for Energy, (2024) *EU energy in figures: statistical pocketbook 2024*. Publications Office of the European Union. https://data.europa.eu/doi/10.2833/802460.

Improving the energy efficiency of devices reduces the energy consumption rate. This is an effective and economically justified method of energy management. If we superimpose changes in the energy mix on this process, we can talk about a general energy trend. World total energy supply by fuel is presented in Tables 2 and 3 and in Figure 1.

Table 2.
World Total Energy Supply by Fuel [Mtoe]

[Mtoe]	2000	2010	2019	2020	2021	2022
Petroleum and Products	3 683	4 152	4 552	4 130	4 376	4 488
Solid Fuels	2 316	3 652	3 870	3 762	4 032	4 106
Gas	2 068	2 736	3 314	3 292	3 477	3 437
Renewables, including:	1 170	1 439	1 876	1 927	2 006	2 080
*Hydro	225	297	366	375	370	374
*Geothermal	52	62	101	107	110	116
*Solar/Wind/Other	8	48	222	249	290	339
*Biofuels and Waste	906	1 065	1 235	1 243	1 284	1 301
Nuclear	675	719	728	698	734	700
Other	23	34	49	48	49	48
Total	9 935	12 732	14 389	13 857	14 674	14 859

Source: European Commission, Directorate-General for Energy, (2024) *EU energy in figures: statistical pocketbook 2024*. Publications Office of the European Union. https://data.europa.eu/doi/ 10.2833/802460.

As shown by the above data, energy consumption in the world has increased by 50% in the last twenty years, from less than 10,000 Mtoe to almost 15,000 Mtoe. A positive trend can be observed related to the increase in the share of renewable energy sources. Energy from renewable sources has almost doubled in value over the last twenty years.

Table 3.
Structure of World Total Energy Supply by Fuel [%]

[%]	2000	2010	2019	2020	2021	2022
Petroleum and Products	37,07%	32,61%	31,64%	29,80%	29,82%	30,20%
Solid Fuels	23,31%	28,68%	26,90%	27,15%	27,48%	27,63%
Gas	20,82%	21,49%	23,03%	23,76%	23,69%	23,13%
Renewables, including:	11,78%	11,30%	13,04%	13,91%	13,67%	14,00%
*Hydro	2,26%	2,33%	2,54%	2,71%	2,52%	2,52%
*Geothermal	0,52%	0,49%	0,70%	0,77%	0,75%	0,78%
*Solar/Wind/Other	0,08%	0,38%	1,54%	1,80%	1,98%	2,28%
*Biofuels and Waste	9,12%	8,36%	8,58%	8,97%	8,75%	8,76%
Nuclear	6,79%	5,65%	5,06%	5,04%	5,00%	4,71%
Other	0,23%	0,27%	0,34%	0,35%	0,33%	0,32%
Total	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%

Source: own study.

The structure of the global energy mix has been improving over the last twenty years. We are observing a clear increase in renewable energy sources. Sources such as wind and photovoltaic cells deserve special attention. Although they constitute only 2.28% of the energy mix, the amount of energy obtained from these sources is growing most dynamically over the period under study. In 2020, these sources accounted for only 0.08% of the energy mix.

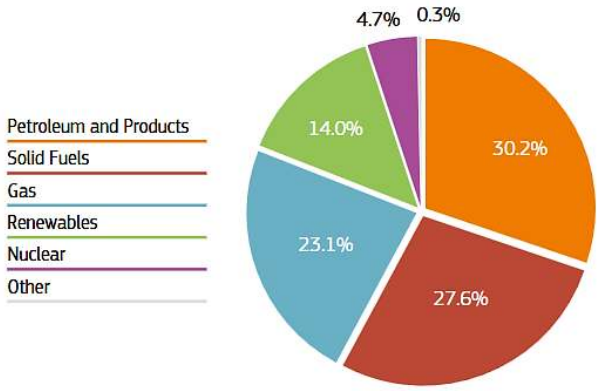

Figure 1. Structure of the total world energy supply by fuel in 2022.
Source: own collaboration.

The structure of the global energy mix in 2022 already includes approximately 14% of energy from renewable sources. This situation looks even more favorable if we look at the energy mix of the European Union, and in particular Poland. Table 4 shows energy production in the EU-27 and Poland in 2019-2022, detailing energy obtained from renewable sources.

Table 4.
Total Energy Supply by Fuel UE-27 and Poland [Mtoe]

[Mtoe]	2019	2020	2021	2022
EU-27 total, including:	618,1	573,1	598,2	562,9
* from renewable sources	227,4	233,5	244,6	243,3
Poland total, including:	62,1	58,0	60,1	59,4
* from renewable sources	12,3	12,5	12,8	13,4

Source: Energy from renewable sources in 2023, GUS, Statistical Office in Rzeszow, Warszawa-Rzeszów 2024, https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/energia/energia-ze-zrodel-odnawialnych-w-2023-roku,3,18.html.

In recent years, in the EU and in Poland, we have observed a general decline in the amount of energy obtained. This decrease in 2022 compared to 2019 amounted to over 9% in the EU, while in Poland in the same period energy production decreased by 4.5%. This was influenced by, among others, a decrease in the energy intensity index of European economies. At the same time, both in the EU and in Poland, we are observing an increase in the volume of energy production from renewable sources. In the EU, during the analyzed period, the production of energy from renewable sources increased by almost 7%, while in Poland by almost 9%. The percentage of energy from renewable sources in the total energy production in the EU and Poland is presented in Table 5.

Table 5.
Strukture of Total Energy Supply by Fuel UE-27 and Poland [%]

[%]	2019	2020	2021	2022
EU-27 total, including:	100,0%	100,0%	100,0%	100,0%
* from renewable sources	36,8%	40,7%	40,9%	43,2%
Poland total, including:	100,0%	100,0%	100,0%	100,0%
* from renewable sources	19,8%	21,6%	21,3%	22,6%

Source: own study.

As shown in the data in Table 5, the share of renewable energy sources in energy production in Poland, although growing dynamically, still remains much lower than in the EU-27. In 2022, renewable energy sources provided over 43% of the energy produced in the EU-27, while in Poland it was only 22.6%.

5. Renewable energy – an alternative or necessity

Currently, fossil fuels dominate as an energy source. Hard coal and brown coal dominate as fuel for electricity generation. In the USA, 30.4% of electricity comes from coal, in India 44%, in England 35% (European Commission, Directorate-General for Energy, 2024). Coal is a fuel often contaminated with sulfur and mercury. To generate 3000 kWh of electricity, 100 kg of carbon dioxide is released into the atmosphere (71.4 kg when burning crude oil, 53 kg when burning natural gas). Environmental and health risks are the biggest drawback of coal-fired

power plants. Sulfur dioxide released into the atmosphere along with carbon dioxide causes lung and respiratory diseases. Fossil fuels as an energy source are no longer a long-term alternative.

Nuclear energy sources, on the other hand, have always been controversial. Nuclear power plants are expensive to build, but then cheaper to operate. Uranium is a relatively cheap fuel and easy to transport. Nuclear reactors can operate for 1-2 years on one charge of uranium. Nuclear power plants do not emit carbon dioxide. Nuclear reactors have triple protection to prevent uncontrolled reaction and radioactive contamination of the area. However, unexpected breakdowns and accidents are possible. In 1979 in Pennsylvania (USA) there was an uncontrolled reaction at the "Three Mile Island" power plant. One reactor was accidentally destroyed and the large amount of radiation caused the need to evacuate a large number of residents. The health risk was very serious. Based on this unfortunate accident, additional security measures and additional crew training were introduced. The revised technology is safer but still controversial. The process of mining and enriching uranium is also controversial due to the danger of radioactive contamination. Removing, transporting and storing spent uranium is also difficult and environmentally hazardous. Spent uranium is cooled in 2-meter-deep water tanks for several weeks. Water in spent uranium cooling tanks becomes highly radioactive. Contamination with such water occurred at the Japanese Fukushima power plant. A large amount of radioactive heavy metals entered the sea, threatening the environment. Several reactors in the US have been closed for safety reasons. These reactors are no longer operational, but they still pose a threat. Dismantling these reactors is very expensive and risky due to the possibility of site contamination. Cooled, spent uranium was until recently transported to underground storage facilities in Nevada. Local residents protested against transporting spent uranium to underground storage facilities for fear of road or rail accidents. The transportation of spent uranium has been suspended. There is only one power plant in the final stage of investment in the USA. No more new nuclear power plants are being built due to negative public reactions and concerns. In 2022, only 18% of electricity generated in the US came from nuclear power plants (even though 30% of the world's nuclear energy is generated in the US).

For the reasons described above, energy from renewable sources is gaining popularity. In 2022, 13% of electricity generated in the US came from renewable sources (www.americangeosciences.org, 2024). In Europe, this indicator reached 43% (Energy from renewable sources, 2023). The use of renewable energy sources has become the main path to achieving sustainable development.

6. Decentralization of the energy market as a method of effective energy management

The energy market has long been monopolized by energy companies. Any kind of monopolization is unfavorable for the customer (energy user). The antitrust law in the USA allows energy users to choose the energy company from which they want to buy energy. This system forces energy companies to fight for customers by reducing prices. A customer whose priority is environmental protection can only purchase renewable energy (mainly wind and photovoltaic). Prices for renewable energy may be a little higher, but a significant number of conscious customers choose this option to protect the environment. The electric transmission lines are owned by another independent company that has a monopoly in a given area. This company's business activities and fees charged are monitored by state authorities. Any fee increase must be justified and approved by the state and customer association.

Renewable energy generation is very dispersed. A large number of customers have their own photovoltaic panels or small wind turbines. There are also a large number of local small energy companies generating electricity mainly from solar and wind. These are private companies that sell energy to the grid. Energy companies are trying to maintain centralized energy distribution at all costs. Energy companies purchase electricity from individual small energy producers (individual customers and small energy companies). This energy is transferred to the central grid and sold centrally to individual users at a much higher price. This is a very economical form of energy management. This system is beneficial for the central energy company, but very disadvantageous for the customer. The electricity produced by the user with solar panels is transmitted to the central grid and then sold, often to the producer's neighbor. Energy transmission involves losses due to the efficiency of the transmission lines. Transmitting electricity to the central grid and then to the user blocks the capacity of transmission lines. When there is a lot of sunlight or a lot of wind, the energy company cannot buy excess energy due to the capacity of transmission lines.

In recent years, decentralization of the electricity market has become possible through the use of specially developed internet programs and smart meters. Electricity in the U.S. can be sold and purchased locally without the involvement of a utility company. Prices are agreed between the seller and the buyer without any mark-up from the energy company. Of course, the seller and buyer pays a small fee (subscription) for using the online energy trading platform. However, these fees are negligible compared to the energy company's overheads. The energy company buys energy at wholesale prices and sells it at retail prices. Direct decentralized energy trading benefits both the seller and the buyer of electricity. Of course, large energy companies are losing their monopoly on energy trading and perceive it as a threat limiting their profits and total control of the energy market.

Electricity prices in a decentralized system are variable and are controlled by the market law of supply and demand. When there is a lot of sunlight or a lot of wind, energy is cheaper. In the evenings, the price of energy may be higher. An individual electricity producer who has the ability to store energy by charging batteries can sell this energy at a higher price during periods of high demand for electricity.

The decentralized energy market and dynamically changing electricity prices allow for effective and economical energy management. Smart energy meters allow you to program the processes of switching on and off various electrical devices (air conditioning, water heating, etc.) depending on energy prices.

7. Local energy market in the conditions of the existing energy network

The buying and selling of electricity between individual customers connected to the electricity grid is called "Peer-to-Peer Energy Trading" (P2P). This is a very beneficial form of selling and buying excess electricity and wind energy between residents of the local community. Online platforms such as Blockchain, PO3, Grid+ and several others allow you to choose the seller and buyer of energy. The price for electricity varies depending on the current supply and demand. The price is agreed between the seller and the buyer. The energy company is not involved in the transaction. The advantages of the local energy market (P2P) are as follows:

- residents without solar panels or wind turbines can buy renewable energy from neighbors at prices lower than the energy company sells,
- residents generating their own electricity can sell it at prices higher than the tariff rates of the energy company,
- electricity does not have to be transmitted over long distances from a centrally located power plant, which reduces the costs of electricity transmission (the cost of energy transmission over long distances can be up to 40% of energy costs),
- local energy comes from renewable sources,
- residents have the opportunity to choose who they buy energy from and can support local energy producers,
- transactions take place between the seller and the buyer of energy (all types of intermediation by energy companies are eliminated),
- all transactions on the blockchain platform are visible to the seller and buyer and are fully secure and objective,
- fees charged for using "blockchain" are very low.

The first global experiment with Peer-to-Peer Trading (P2P) took place in Brooklyn, New York in 2016. Since then, the idea of "P2P" has spread around the world. The platforms for selling and purchasing energy have been improved. They are safe and transparent for the seller and buyer. However, the implementation of "P2P" is very slow. Energy companies are not interested in losing their monopoly on the sale of electricity.

8. Conclusions

To summarize the analysis of the energy problem, the following conclusions can be drawn:

1. The use of fossil fuels as an energy source to generate electricity should be gradually limited. The share of renewable energy sources in the energy mix is growing worldwide, especially in the EU-27, where the share of renewable energy sources in total energy production is approximately 43%.
2. Nuclear energy is very controversial. Existing nuclear power plants were mostly built in the 1960s and 1970s. Currently, much fewer new nuclear power plants are being built due to the high cost of construction and negative reactions and justified public concerns. Transport and storage of spent uranium is also a problem.
3. Using renewable energy sources to generate electricity is no longer an alternative and has become a necessity.
4. Rapidly developing modern computer technology and artificial intelligence allows for local energy trading bypassing energy companies. This ensures energy supplies (energy security) for small consumers in the event of failure of large power plants. Smart electricity meters allow you to stabilize energy demand through changing energy prices in accordance with the law of supply and demand. Smart meters allow you to turn selected electrical devices off and on depending on the current energy price.
5. Modern computer technology creates new opportunities for energy trading. However, legal regulations are required allowing for the decentralization of the energy market and the implementation of direct energy trading bypassing energy companies. Legal regulations must also define the principles of operation of the local energy market.

References

1. Bałamut, A., Gryz, J., Ruszel, M., Szurlej, A. (2024). Rola klastrów energii w kształtowaniu samowystarczalności energetycznej i bezpieczeństwa na poziomie lokalnym w Polsce. *Rynek energii, No 4 (173)*, pp. 3-11.
2. Dołęga, W. (2022). Efektywność energetyczna gospodarki krajowej – wybrane aspekty. *Przegląd Elektrotechniczny, R. 98, No. 8/202*, pp. 118-122.
3. European Commission, Directorate-General for Energy (2024). *EU energy in figures: statistical pocketbook 2024*. Publications Office of the European Union. Retrieved from: https://data.europa.eu/doi/10.2833/802460.
4. GUS (2024). *Energy from renewable sources in 2023*. Warszawa/Rzeszów: Statistical Office in Rzeszow. Retrieved from: https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/energia/energia-ze-zrodel-odnawialnych-w-2023-roku,3,18.html.
5. https://www.money.pl/gospodarka/wydatki-na-energie-odnawialna-bija-rekordy-siegaja-poziomu-2-bln-dol-7083984520800864a.html, 19.03.2024.
6. Janicki, W. (2024). Population optimum as a remedy for demographic threats? Confrontation of global and local perspectives. *Przegląd Geopolityczny, No. 48*, pp. 46-68.
7. KIGEiT – Krajowa Izba Gospodarcza Elektroniki i Telekomunikacji (2022). Inteligentne liczniki energii elektrycznej. *Nowa Energia, No. 4(85)*, pp. 8-12.
8. Komunitat Komisji - *Wytyczne w sprawie pomocy państwa na ochronę klimatu i środowiska oraz cele związane z energią* (2022). Dz.U. C 80 z 18.2.2022, pp. 1-89.
9. *List of Member State measures approved under Temporary Crisis Transition Framework.* Retrieved from: https://competition-policy.ec.europa.eu/document/download/1b687754-5eab-4447-bcbb-da0eb9ae61b9_en?filename=State_aid_TCTF_decisions.pdf, 19.03.2024.
10. Mól, B., Bargiel, J., Halinka, A., Sowa, P. (2022). Lokalne bezpieczeństwo energetyczne w kontekście nowych zagrożeń globalnych. *Przegląd Elektrotechniczny*, *R. 98, No. 12/202*, pp. 283-288.
11. Peet, J. (2004), Economic systems and energy, conceptual overview. *Encyclopedia of Energy, Vol. 6*, pp. 103-115.
12. Plich, M., Skrzypek, J. (2016). Trendy energochłonności polskiej gospodarki. *Wiadomości statystyczne, No. 7*, p. 16.
13. Poborski, M., Kraska, E.M. (2023). Krajowe struktury demograficzne w globalnej perspektywie. *Przegląd Prawno-Ekonomiczny*, *1*, pp. 9-28. Retrieved from: https://doi.org/10.31743/ppe.14742.
14. Sochacki, M. (2023). Nowe technologie na rzecz miniaturyzacji i poprawy sprawności energetycznej urządzeń elektrycznych. *Materiały XLV seminarium "System oceny*

zgodności wyrobów elektronicznych i elektrotechnicznych". Warszawa: Polskie Stowarzyszenie na rzecz Badań Technicznych i Atestacji TEST-Q, pp. 27-29.

15. Wojciechowska, N. (2021). Renewable energy sources as a catalyst for the introduction of the circular economy model. *Zeszyty Studenckie Wydziału Ekonomicznego Uniwersytetu Gdańskiego "Nasze Studia", No. 11*, pp. 104-117.
16. www.americangeosciences.org/critical-issues/faq/what-are-major-sources-and-users-energy-united-states, 15.10.2024.
17. Zawadzka, M., Hofman, M. (2024). *Mechanizmy pomocowe na rozwój zielonej gospodarki – jak Polska wypada na tle świata i Unii Europejskiej?* Retrieved from: https://crido.pl/blog-business.

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TOURIST INFRASTRUCTURE OF SILESIA'S INDUSTRIAL MONUMENTS ROUTE IN THE CONTEXT OF THE X-MINUTE CITY CONCEPT

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Purpose: The aim of the paper is to assess the accessibility of Google Points of Interest surrounding the Industrial Monuments Route (IMR) sites, using travel time and distance criteria, within the framework of the X-minute cities concept.
Design/methodology/approach: To achieve the goal, the data obtained from Google Maps analyzed was used, focusing on Points of Interest (POIs) in the proximity of IMR sites.
Findings: The tourist infrastructure around the sites of IMR has been identified, along with the potential of the x-minute city concept to assess the surroundings of tourist attractions.
Research limitations/implications: IMR might be a specific case of an industrial route, because all of its sights are located within a large agglomeration. Other thematic tourist routes might differ significantly from this example.
Practical implications: The research can serve as a starting point for spatial planning or the creation of a collaboration network.
Social implications: The implementation of the research can serve as a basis for making decisions about transforming the area and influencing its quality.
Originality/value: The application of the 15-minute city concept perspective to study the surroundings of a tourist attraction.
Keywords: 15-minute city, the Industrial Monument Route, post-industrial heritage.
Category of the paper: case study.

1. Introduction

Silesia is a unique region in Poland, primarily known for its rich natural resources. It was in this region that the largest industrial plants of the 19th and 20th centuries were located. Following socio-economic changes from a centrally planned economy to a market-based one, many of these plants became unprofitable. Attempts at restructuring and privatization allowed

some to survive, while others were closed. This resulted in the emergence of post-industrial areas, often degraded by human activity, which required new functions, one of which was tourism, leading to the development of industrial heritage tourism sites preserving the culture and traditions of industrial professions.

The shift of a company's focus to tourism does not always lead to the development of tourism infrastructure around the site. This happens despite the fact that it presents an excellent opportunity to create urban spaces that are functional and accessible for both tourists and local residents. Factors such as land ownership, building characteristics, and urban planning may play a role. However, appropriate actions can positively impact the city's image and local entrepreneurship. In this context, the concept of the 15-minute city, where key services are within 15 minutes on foot or by bike (Moreno et al., 2021), can inspire the creation of sustainable spaces that combine tradition with modern urban planning requirements.

To make such actions effective, it is crucial to thoroughly understand the current state of infrastructure and its needs. Therefore, the aim of this paper is to assess the accessibility of Points of Interest around the Industrial Monuments Route (IMR) in the Silesian Voivodeship by using one of the most commonly used map service – Google Maps. This study focused on Points of Interest located within a 1500-meter radius from the sites belonging to the Industrial Monuments Route

Such a study could be of great importance for the integration of tourist infrastructure with the concept of sustainable urban spatial development, especially in the context of modern ideas addressing contemporary needs, such as reducing the number of cars in cities, promoting a healthy lifestyle, better urban planning, and reducing pollution.

To achieve this goal, it is essential to clarify the concepts of the 15-minute city and the tourist attraction.

2. Theoretical background

A tourist attraction is a place that encourages people to leave their place of residence (Lew, 1987). Industrial heritage tourist attractions, on the other hand, are sites that refer to industrial history and traditions, often resulting from repurposing closed factories while attempting to preserve the memory of the heritage (Garrod, Fyall, 2000; Szromek et al., 2021). These places serve many different functions and purposes (Vukosav, 2015), providing entertainment, education, or preserving artifacts from the past. Additionally, creating such tourist attractions is an instrument for regional restructuring and economic development. This is exemplified by the Ruhr Area (Germany), where significant structural changes took place due to the decline of the mining and steel industries. Post-industrial areas were transformed into tourist attractions within the Emscher Park (Ćopić et al., 2014). In Poland, particular attention should be given to

the tourist attractions located in the Silesian Voivodeship. These attractions are part of the Silesian Industrial Monuments Route (IMR) (szlakzabytków.pl). Although they have been the subject of numerous studies (Szromek et al., 2021; Bogacz et al., 2019; Bujok et al., 2015), this area has not been fully analyzed, especially in terms of its surroundings. Therefore, a study was conducted on the tourist infrastructure located near these attractions, using some of the principles of the 15-minute city concept.

The "15-minute city" is an urban planning concept rooted in the idea of "chrono-urbanism". It suggests that quality of life is inversely proportional to the time spent on transportation, particularly car travel (Moreno et al., 2021). The core premise of this model is that all essential services for residents should be accessible within a 15-minute walk or bike ride. This model is based on four key principles. In addition to proximity (the 15-minute range), it emphasizes density, which ensures an optimal population level considering pollution and service provision; diversity, which provides access to a wide range of services; and universality, which underscores independence from an individual's socio-economic status (Murgante et al., 2023).

The concept promotes the creation of self-sufficient residential areas with access to services such as employment, healthcare, education, and entertainment (Bocca, 2021; Ferrer-Ortiz et al., 2022). The idea was first introduced in 2016 and became widely known when Anne Hidalgo used it in her campaign for Mayor of Paris, aiming to solve the city's traffic problems (Teixeira, 2024). It gained even more popularity during the Covid-19 pandemic, as people began to value local services and shorter commutes (Moreno et al., 2021).

However, the idea is not entirely new (Pozoukidou, Chatziyiannaki, 2021). It draws from historical concepts like the Garden City, the Neighbourhood Unit, and later, the Smart City (Howard, 1902; Khavarian-Garmsir et al., 2023a; Rohe, 2009), while aligning with contemporary trends emphasizing the need for sustainable urban development (Khavarian-Garmsir et al., 2023b).

The concept has also served as a foundation for new or modified urban planning models. One notable approach is the idea of the x-minute city (Logan et al., 2022). Unlike the 15-minute model, this concept does not adhere to a fixed time frame for accessibility. Instead, it acknowledges that the characteristics of specific areas may shorten or lengthen access times to infrastructure. Consequently, one can speak of 10-minute or 30-minute cities. This flexible approach not only facilitates city planning but also enables the analysis of current conditions and the proposal of targeted development strategies.

Another example of applying the 15-minute city concept is its use in assessing tourism potential. Jasion (2023) identified a sports fan visiting a stadium as the central point of reference for evaluating the accessibility of key tourist infrastructure. Similarly, Herman (2023) used a tourist arriving at a railway station as the focal point to assess infrastructure accessibility from their perspective. This approach enables the application of the concept to the development of areas surrounding tourist attractions, enhancing their functionality and appeal.

The above examples highlight the versatility of the 15-minute city concept and its applicability in research on tourist attractions and their surroundings, particularly in terms of tourism infrastructure and its accessibility.

Tourism infrastructure itself can be understood in different ways. On one hand, it can be viewed broadly as all facilities that help tourists meet their daily needs (Panasiuk, 2008). Alternatively, it can be interpreted more narrowly, such as being seen as a bridge connecting resources, for example, linking people and nature (Humagi et al., 2021). Regardless of the chosen interpretation, from a practical perspective, it represents a functional entity with a specific geographic location.

This same practical perspective applies to the concept of a Point of Interest (POI). According to Google, a POI is a pin on the map with precise coordinates, accompanied by a name recognized by Google (Google, 2024). In tourism, POIs are closely tied to tourist infrastructure. They are essential for identifying and searching for places through Google's search engine, serving as a key tool for exploring destinations.

3. Methods

The subject of the study was the Industrial Monuments Route of the Silesian Voivodeship, which, during the research period, comprised of 42 tourist sites. The focus of the research was the tourist infrastructure surrounding these sites, facilitating the fulfillment of cognitive, transport, and catering needs. The data used in the analysis was obtained from Google Maps and dated on February 2024. It included a list of points located within a 1500-meter radius of each IMR site which is an equivalent of 30 minutes' walk. According to the Points of Interest (POI) classification used by Google, the list featured hotels, tourist attractions, dining establishments, bars, cafes, grocery stores, museums, parks, and public transport stops. For all the objects identified in this manner, the list was supplemented with the walking time from the tourist site to the given POI, and, if the object had reviews on Google, its average rating and the number of reviews were also recorded.

4. Results

4.1. Overall characteristics of the obtained data

The collected dataset consisted of 4739 records, with each record corresponding to a single POI located within the vicinity of one of the IMR sites. The number of individual POI types is presented in Table 1.

Table 1.
The number of POI types within 1500m radious of IMR

Type	N	Share
gastronomy	999	21.08%
transport	777	16.40%
hotels	647	13.65%
attractions	624	13.17%
park	551	11.63%
convenience_store	362	7.64%
bar	297	6.27%
cafe	269	5.68%
art_gallery	107	2.26%
muzeum	106	2.24%
TOTAL	4739	100,00%

Source: Own work.

As one can note, the most common type of POI in the studied case are public gastronomy points (21.08%), public transport stops (16.40%) and hotels (13.65%). Whereby high culture sites like art galleries (2.26%) and museums (2.24%) were least occurring types of POI's.

The average number of POIs in the specified range from a site was 132. Whereby 15 of the IMR sites have more than that, and the remaining 27 less. The indicates that the distribution of POI among IMR sites is right-skewed, with was by a histogram of this variable, that was shown in figure 1.

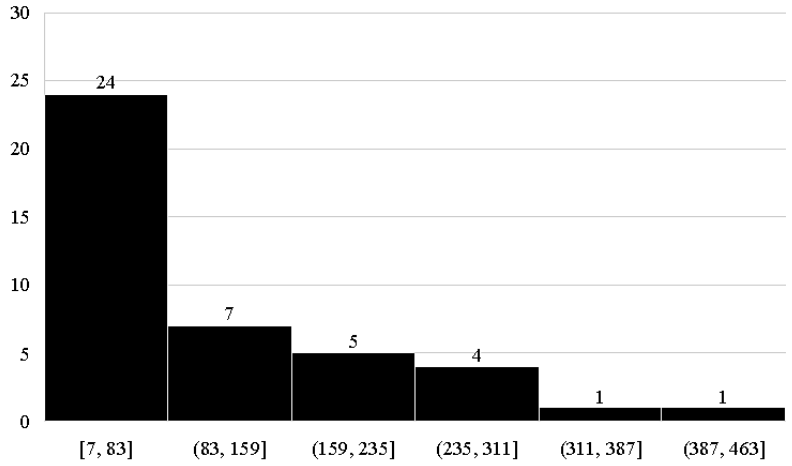

Figure 1. Histogram of POIs numbers in the range of IMR sites.
Source: Own work.

The strong right-skew explains why most of the sites have less than the average number of POI, where most of them fit into the range between 7 and 83, and the median value was 102.

In table 2 the number of all POI's for each site was presented. One might expect that the city where a given site is located would affect the number of POI most, and the sites with most POI's would be in the capital city of the Silesian voivodeship – Katowice, but the results show that this is not a rule. The site with most POI's was Stara Fabryka (Old Factory) in Bielsko-Biała, flowed by Muzeum Śląskie (Silesian Museum) in Katowice and Muzeum Górnictwa Rud Żelaza (Iron Ore Mining Museum) in Częstochowa. Similarly, a site that is located in the

4th most populated city in Silesia – Gliwice, was the one with least POI. This leads to the conclusion that the specific location of a site, especially the distance to town center is more impactful in this aspect.

Table 2.
The number of POI's within 1500m radious of given IMR site

Site	N	Share	Site	N	Share
Stara Fabryka	388	8.19%	Park Tradycji	73	1.54%
Muzeum Śląskie	361	7.62%	Muzeum Techniki Sanitarnej	68	1.43%
Muzeum Górnictwa Rud Żelaza	285	6.01%	Fabryka Porcelany	67	1.41%
Muzeum Drukarstwa	276	5.82%	Galeria Sztuki Współczesnej - Elektrownia	66	1.39%
Browar Zamkowy	252	5.32%	Muzeum Hutnictwa Cynku	63	1.33%
Muzeum Produkcji Zapałek	245	5.17%	Szyb Wilson	62	1.31%
Centrum Wycieczkowe Tyskich Browarów Książęcych	196	4.14%	Giszowiec	61	1.29%
Muzeum Hutnictwa	193	4.07%	Nikiszowiec	61	1.29%
Muzeum Ustrońskie	193	4.07%	Centralne Muzeum Pożarnictwa	52	1.10%
Szyb Prezydent	187	3.95%	Stary Młyn Muzeum Dawnych Rzemiosł	49	1.03%
Kopalnia Ćwiczebna Sztygarka	169	3.57%	Szyb Maciej	45	0.95%
Kopalnia Guido	131	2.76%	Zabytkowa Kopalnia Srebra	41	0.87%
Muzeum Prasy Śląskiej	123	2.60%	Stacja Biblioteka MBP w Rudzie Śląskiej	38	0.80%
Oddział Odlewnictwa Artystycznego	122	2.57%	Familoki - Czerwionka	37	0.78%
Wieże KWK Polska	122	2.57%	Zabytkowa Kopalnia Ignacy w Rybniku	32	0.68%
Muzeum Historii Kolei	116	2.45%	Muzeum Chleba, Szkoły i Ciekawostek	30	0.63%
Sztolnia Królowa Luiza	112	2.36%	Sztolnia Czarnego Pstrąga	26	0.55%
Górnośląskie Koleje Wąskotorowe	103	2.17%	Zabytkowa Stacja Kolei Wąskotorowej w Rudach	26	0.55%
Radiostacja Gliwice	83	1.75%	Muzeum Browaru Żywiec	15	0.32%
Kolonia Robotnicza Ficinus	78	1.65%	Muzeum Energetyki	9	0.19%
Browar Obywatelski	76	1.60%	Zabytkowa Stacja Wodociągowa Zawada	7	0.15%

Source: Own work.

Although the search radius for POI was limited to the radial distance from a site to 1500 m, some of the found locations are hard to reach by pedestrians and therefore limit the accessibility and walkability of a tourist site. Therefore the next step of the analysis was to examine the detailed information on distance from sites to different types of POI.

4.2. POI walking distance to sites analysis

The bare number of POIs near a tourist site does not fully reflect how accessible they are. A significant impact on the accessibility of a site to a tourist is actually if his or hers needs after the visit at a site can be satisfied in a short time and can be reached without entering a vehicle. Therefore in figure 2 the number of POI in the proximity of IMR sites was additionally divided into ranges of time required to reach them by a pedestrian.

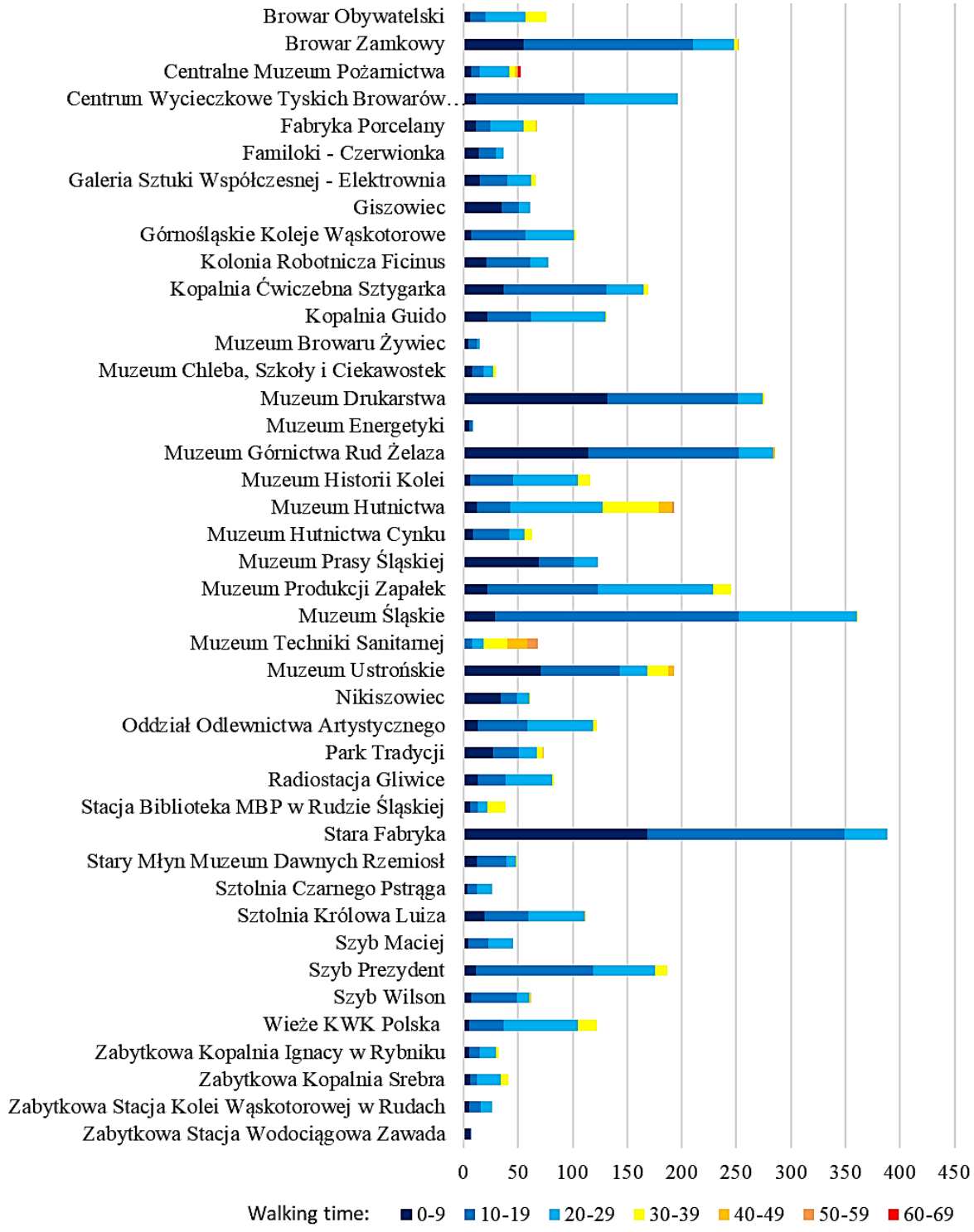

Figure 2. The number of POI within given walking range from IHR sites.

Source: Own work.

Most of the sites have high share of POI within walking range under 29 min. In cases of IMR sites that are located directly in city center over half of the identified POI are reachable in 9 min. or less walking time. One of the sites strongly differs from the rest in this aspect – Muzeum Techniki Sanitarnej (Sanitary Technology Museum) in Gliwice. Moreover the presented data indicates that most Points of Interest near the sites of IMR are within a short

walking distance, primarily in the 10-19 minute range, which constitutes the largest number of records. The second-largest group of POIs falls within the 0-9 minute range, highlighting the high accessibility of tourist infrastructure in close proximity to the sites. Noticeably fewer POIs are located at greater distances, with the number of points decreasing significantly in categories beyond a 30-minute walk.

Among the sites with the highest infrastructure accessibility, Stara Fabryka stands out for having the most POIs within a 9-minute walking distance, while Muzeum Śląskie and Szyb Prezydent dominate in the 10-19 minute category. Sites such as Browar Zamkowy and Muzeum Górnictwa Rud Żelaza have a greater number of POIs in the 20-29 minute range, suggesting a more dispersed infrastructure around these locations.

The sites with the least accessible infrastructure include Muzeum Energetyki, with only 9 POIs in its vicinity, mostly within a 9-minute walk, and Sztolnia Czarnego Pstrąga and Muzeum Browaru Żywiec, which have relatively few POIs in any time category. POIs located at greater distances, such as in the 40-49 minute range or over 50 minutes, are rare, indicating limited extended infrastructure accessibility.

The overall distribution of data confirms that tourist infrastructure is most concentrated within a short distance of IMR sites, enhancing their appeal to visitors. Muzeum Śląskie, Stara Fabryka, and Szyb Prezydent stand out as locations with the densest infrastructure across various time categories, making them particularly attractive to tourists.

The next step of the analysis was to investigate if there are clear accessibility differences between different POI types. Figure 3 Shows the share of walking time ranges from IMR sites to a given type of POI.

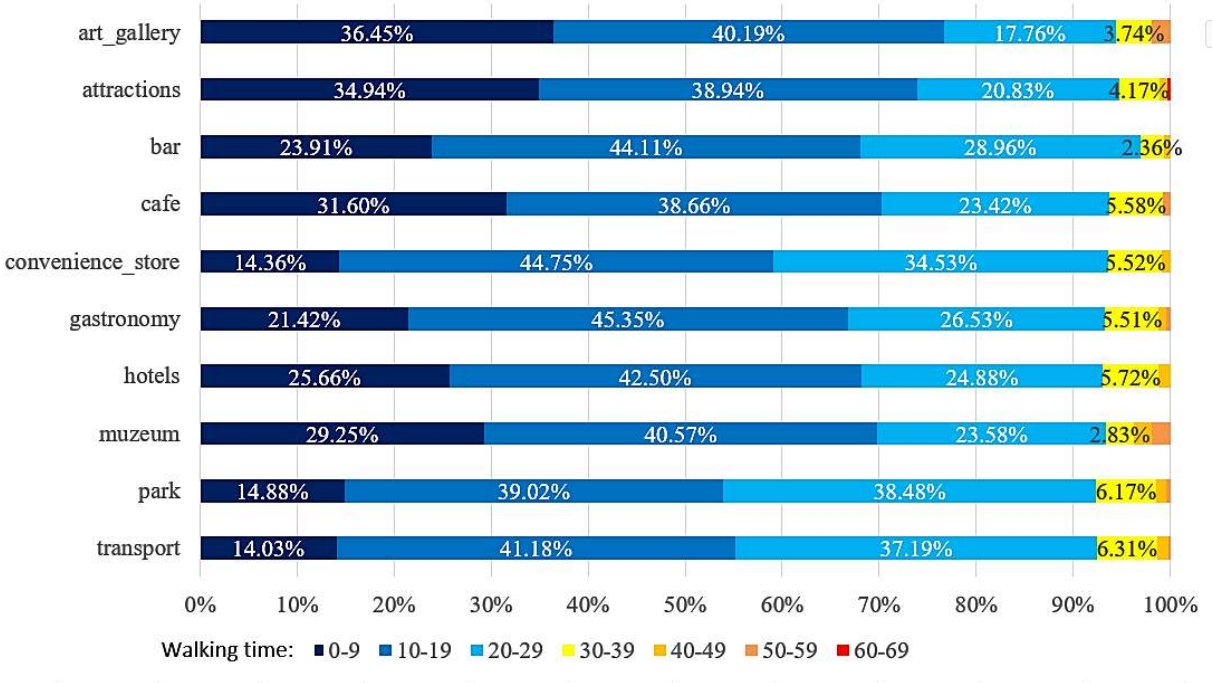

Figure 3. The walking time ranges from IMR sites.

Source: Own work.

Overall, the largest percentage of POIs (41.97%) is concentrated within the 10-19 minute walking range, followed by 29.01% in the 20–29 minute range and 22.52% in the 0-9 minute range. POIs located beyond a 30-minute walking time are sparse, with percentages dropping significantly for these categories.

For gastronomy, which is the most numerous category, 45.35% of POIs are within the 10-9 minute range, followed by 26.53% within 20-29 minutes, and 21.42% within 0-9 minutes. Transport and parks show a similar distribution, with the majority of their POIs in the 10-19 and 20-29 minute categories, accounting for over 75% of their total for both types. Hotels have a slightly higher proportion within the 10-19 minute range (42.50%) and a notable share in the 0-9 minute category (25.66%).

Museums and art galleries differ slightly, with higher proportions of their POIs in the 0-9 minute range (29.25% and 36.45%, respectively). This indicates that cultural POIs are often more accessible within shorter walking distances. Cafes and bars are predominantly located within the 10-19 minute range (38.66% and 44.11%, respectively), though a significant portion of cafes is also within 0-9 minutes (31.60%).

Attractions, while spread out across various ranges, have the highest percentage (34.94%) within 0-9 minutes, indicating that many key tourist sites are highly accessible. Similarly, art galleries have a notable concentration of POIs in the 0-9 minute range, with 36.45% of their total, followed by 40.19% in the 10-19 minute category.

In summary, the percentage breakdown confirms the earlier observation that most POIs are concentrated within a 20-minute walking range of IHR sites. The data also highlights variations in accessibility among different categories, with cultural and attraction-based POIs tending to be closer, while facilities like transport, parks, and gastronomy are slightly more dispersed.

The final step of the analysis was to investigate the distribution of POI types among given IHR sites. The numbers of POIs of given type within the range of a given IMR site from table 3 were used to prepare the visualization of POIs type share in figure 4.

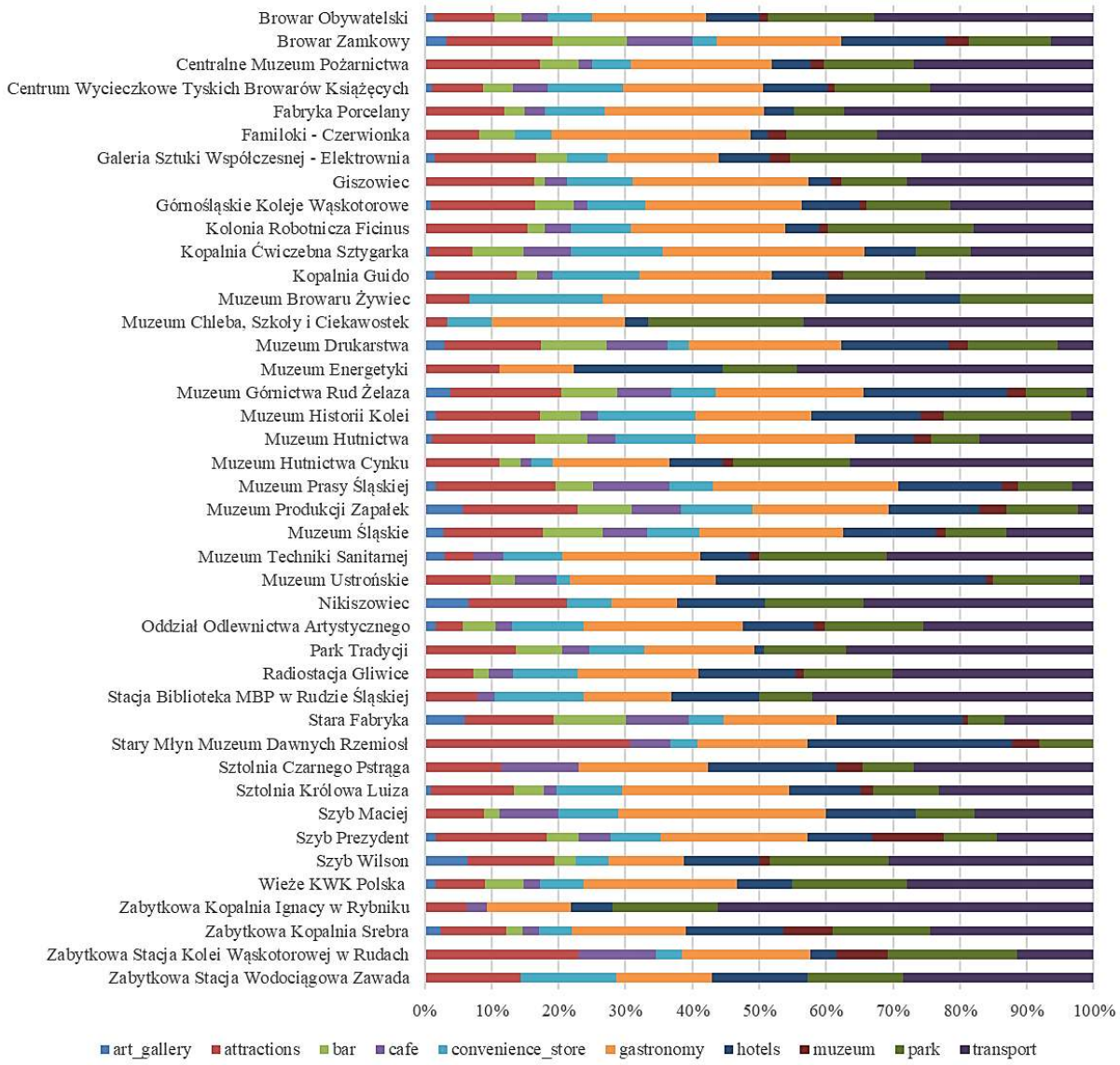

Figure 4. The distribution of given POI types among IHR sites.

Source: Own work.

Table 3.
The number of given POIs within 1500 m from given IMR site

Site	N	Share	Site	N	Share
Stara Fabryka	388	8.19%	Park Tradycji	73	1.54%
Muzeum Śląskie	361	7.62%	Muzeum Techniki Sanitarnej	68	1.43%
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Muzeum Ustrońskie	193	4.07%	Centralne Muzeum Pożarnictwa	52	1.10%
Szyb Prezydent	187	3.95%	Stary Młyn Muzeum Dawnych Rzemiosł	49	1.03%

Cont. table 3.

Kopalnia Ćwiczebna Sztygarka	169	3.57%	Szyb Maciej	45	0.95%
Kopalnia Guido	131	2.76%	Zabytkowa Kopalnia Srebra	41	0.87%
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Radiostacja Gliwice	83	1.75%	Muzeum Browaru Żywiec	15	0.32%
Kolonia Robotnicza Ficinus	78	1.65%	Muzeum Energetyki	9	0.19%
Browar Obywatelski	76	1.60%	Zabytkowa Stacja Wodociągowa Zawada	7	0.15%

Source: Own work.

Overall, gastronomy accounts for the largest overall share, making up 21.08% of POIs, followed by transport at 16.40% and hotels at 13.65%. Attractions represent 13.17%, while art galleries and museums are the least represented categories at 2.26% and 2.24%, respectively.

Browar Obywatelski stands out for its high proportion of transport-related POIs, which make up 32.89%, alongside gastronomy at 17.11% and parks at 15.79%. Browar Zamkowy has a more diverse distribution, with gastronomy at 18.65%, attractions at 15.87%, and hotels at 15.48%. Fabryka Porcelany shows a strong focus on transport, which constitutes 37.31%, and gastronomy at 23.88%, indicating its utility-oriented nature. Familoki - Czerwionka has a similar emphasis on gastronomy at 29.73% and transport at 32.43%, but other categories are sparsely represented.

Muzeum Śląskie offers a balanced profile, with gastronomy making up 21.61%, followed by attractions at 14.96% and hotels at 13.85%. Muzeum Górnictwa Rud Żelaza has a similar balance, with gastronomy accounting for 22.11%, hotels at 21.40%, and attractions at 16.49%. These locations offer a mix of practical amenities and cultural experiences. In contrast, Muzeum Browaru Żywiec has a more concentrated profile, with 33.33% in gastronomy and smaller shares in hotels and parks, limiting its appeal to a narrower audience.

Kopalnia Guido has a well-distributed profile, with 19.85% in gastronomy, 12.98% in convenience stores, and smaller but significant shares in transport and attractions. Stara Fabryka features a wide range of POIs, with the largest share in hotels at 18.81%, followed by gastronomy at 17.01% and attractions at 13.40%, making it a comprehensive destination.

Locations such as Zabytkowa Kopalnia Srebra and Szyb Wilson show notable shares in transport and gastronomy but have lower representation in other categories. Muzeum Energetyki and Zabytkowa Stacja Wodociągowa Zawada have profiles heavily dominated by transport or parks, with limited variety in other categories. These sites could benefit from expanding their offerings to attract a broader range of visitors.

Sites with a more even distribution of POIs, such as Browar Zamkowy and Stara Fabryka, tend to appeal to diverse visitor groups, while those with a narrow focus, like Muzeum Browaru Żywiec or Muzeum Energetyki, may attract niche audiences but lack general appeal. The data

suggests that locations with strong representations in gastronomy, transport, and hotels provide more comprehensive visitor experiences, while sites with limited POI diversity might consider adding complementary services to enhance their attractiveness.

5. Discussion and summary

By utilizing elements of the 15-minute city concept and urban Points of Interest (POIs), it is possible to assess the environment surrounding tourist attractions. The conducted research indicated that for the analyzed IMR sites, the number of POIs is asymmetrical, meaning that most of the studied sites do not exceed the average number of POIs. This is influenced by objects located in city centers, such as the Old Factory in Bielsko-Biała, which has the highest number of identified POIs in its vicinity. On the other hand, it was observed that due to the specificity of industrial heritage tourist attractions, some sites are located in less accessible areas, outside residential zones or in sparsely populated areas. An example of this is the Zawada Water Station. Such a location limits the number of POIs nearby.

The presented data shows that most of the identified POIs within a 1500-meter range are within a 0-20 minute walk. This is a distance conducive to walking decisions. However, it is not the only factor influencing the decision. This relates to the concept of "walkability," which consists of a set of factors influencing the decision to take a walk (Southworth, 1997). These factors can be categorized into usability, safety, comfort, and the attractiveness of the walking route (Abdelfattah et al., 2022).

The presence of POIs near IMR sites does not always enhance the tourist offering of the attraction. In order for visitors to take advantage of other services, they must be actively promoted. This is confirmed by Sormaz et al. (2016), who characterize the foodservice industry, highlighting the need for support and promotion, emphasizing that it contributes to regional development.

The conducted research also demonstrated that using elements of the 15-minute city concept along with Google POI effectively allows for an understanding of the surroundings of a tourist attraction in terms of tourist infrastructure. Such preliminary analysis can provide valuable insights for landowners or municipal authorities regarding planned investments or serve as one of the elements in assessing the tourism potential of a given area. From the perspective of local governments, the research can act as an initiative for introducing changes to the city structure, ultimately contributing to its development. For entrepreneurs, it may serve as a signal to, for example, establish collaborations or network tourism products.

Future studies could focus on w wider set of tourist objects and expand the analysis on a larger scale. Moreover, data obtained for such wide set could be used to develop a scoring method, similar to the walkability score, which would allow for a systematized and more objective comparison between tourist sites.

References

1. Abdelfattah, L., Deponte, D., Fossa, G. (2022). The 15-minute city: interpreting the model to bring out urban resiliencies. *Transportation research procedia, 60*, pp. 330-337.
2. Apriyanti, M.E., Sumaryoto, Meirinaldi (2024). The Importance of Tourism Infrastructure in Increasing Domestic and International Tourism. *International Journal of Research in Vocational Studies (IJRVOCAS), 3(4),* pp. 113-122. Retrieved from: https://doi.org/ 10.53893/ijrvocas.v3i4.46.
3. Bocca, A. (2021). Public space and 15-minute city. *TeMA-Journal of Land Use, Mobility and Environment*, *14(3)*, pp. 395-410.
4. Bogacz-Wojtanowska, E., Góral, A., Bugdol, M. (2019). The role of trust in sustainable heritage management networks. case study of selected cultural routes in Poland. *Sustainability*, *11*(10), *2844*.
5. Bujok, P., Klempa, M., Jelinek, J., Porzer, M., Rodriguez Gonzalez, M.A.G. (2015). Industrial tourism in the context of the industrial heritage. *Geojournal of Tourism and Geosites*, *15(1)*, pp. 81-92.
6. Ćopić, S., ĐorđevićA, J., Lukić, T., Stojanović, V., Đukičin, S., Besermenji, S., Tumarić, A. (2014). Transformation of industrial heritage: An example of tourism industry development in the Ruhr area (Germany). *Geographica Pannonica*, *18*(2), pp. 43-50.
7. Ferrer-Ortiz, C., Marquet, O., Mojica, L., Vich, G. (2022). Barcelona under the 15-minute city lens: Mapping the accessibility and proximity potential based on pedestrian travel times. *Smart Cities*, *5(1)*, pp. 146-161.
8. Florentina-Cristina, M., George-Laurenţiu, M., Andreea-Loreta, C., Constantin, D.C. (2014). Conversion of industrial heritage as a vector of cultural regeneration. *Procedia-Social and Behavioral Sciences*, *122*, pp. 162-166.
9. Garrod, B., Fyall, A. (2000). Managing heritage tourism. *Annals of tourism research*, *27*(3), pp. 682-708.
10. Herman, K. (2023). The Analysis of Accessibility of Tourism Infrastructure in the Context of X-Minutes Cities: a Case Study of the City of Zabrze. *Scientific Papers of Silesian University of Technology. Organization & Management [Zeszyty Naukowe Politechniki Śląskiej. Seria Organizacji i Zarządzanie], 189*.
11. Howard, E. (1902). *Garden Cities of Tomorrow*. London: S. Sonnenschein & Co., Ltd.
12. Jasion, A. (2023). Dostępność przestrzenna wybranych usług wokół łódzkich stadionów piłkarskich w oparciu o ideę miasta 15-minutowego. *Czasopismo geograficzne*.
13. Khavarian-Garmsir, A.R., Sharifi, A., Hajian Hossein Abadi, M., Moradi, Z. (2023a). From garden city to 15-minute city: a historical perspective and critical assessment. *Land, 12(2)*, p. 512.

14. Khavarian-Garmsir, A.R., Sharifi, A., Sadeghi, A. (2023b). The 15-minute city: Urban planning and design efforts toward creating sustainable neighborhoods. *Cities, 132, 104101*.
15. Lew, A.A. (1987). A framework of tourist attraction research. *Annals of tourism research*, *14(4)*, pp. 553-575.
16. Logan, T.M., Hobbs, M.H., Conrow, L.C., Reid, N.L., Young, R.A., Anderson, M.J. (2022). The x-minute city: Measuring the 10, 15, 20-minute city and an evaluation of its use for sustainable urban design. *Cities, 131, 103924*.
17. Moreno, C., Allam, Z., Chabaud, D., Gall, C., Pratlong, F. (2021). Introducing the "15-Minute City". *Sustainability, resilience and place identity in future post-pandemic cities. Smart cities, 4(1)*, pp. 93-111.
18. Murgante, B., Patimisco, L., Annunziata, A. (2023). Developing a 15-minute city: A comparative study of four Italian Cities-Cagliari, Perugia, Pisa, and Trieste. *Cities, 146, 104765.*
19. Panasiuk, A. (2008). *Ekonomika Turystyki.* Warszawa: PWN.
20. Pozoukidou, G., Chatziyiannaki, Z. (2021). 15-Minute City: Decomposing the new urban planning eutopia. *Sustainability, 13(2),* p. 928.
21. Rohe, W.M. (2009). From local to global: One hundred years of neighborhood planning. *Journal of the American planning association, 75(2)*, pp. 209-230.
22. Sormaz, U., Akmese, H., Gunes, E., Aras, S. (2016). Gastronomy in tourism. *Procedia Economics and Finance*, *39*, pp. 725-730.
23. Southworth, M. (1997). Walkable suburbs. An evaluation of neo-traditional communities at the urban edge. *Journal of the American Planning Association, 63(1)*, pp. 28-44.
24. Szromek, A.R., Herman, K., Naramski, M. (2021). Sustainable development of industrial heritage tourism–A case study of the Industrial Monuments Route in Poland. *Tourism Management*, *83, 104252*.
25. Teixeira, J.F., Silva, C., Seisenberger, S., Büttner, B., McCormick, B., Papa, E., Cao, M. (2024). Classifying 15-minute Cities: A review of worldwide practices. *Transportation Research Part A: Policy and Practice*, *189*, *104234*.
26. Vukosav, S., Garaca, V., Curcic, N., Bradic, M. (2015). *Industrial Heritage of Novi Sad in the Function of Industrial Tourism: The Creation of New Tourist Products*. International Scientific Conference "Geobalcanica".

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INDIVIDUAL PENSION SECURITY ACCOUNTS – DEMOGRAPHIC AND ORGANISATIONAL STRUCTURE

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Purpose: The purpose of this study was to present the situation of one of the basic components of the third pillar of the Polish pension insurance system, i.e. the Individual Pension Security Accounts (IPSA; Polish: IKZE). The main focus was the changing demographic structure of the IPSA participants. This is of great importance in view of the ageing of the Polish population and social security for the old age.
Design/methodology/approach: The objective was achieved by analysing statistical data obtained from the web pages of the Polish Financial Supervision Authority (FSA; Polish: KNF). The method used was *desk research*, i.e. the study and analysis of official statistics documents, reports, publications, statistical yearbooks, etc. This method is also called secondary research or complementary research, as it is based on the analysis of already existing available data from various sources, such as the press, the Internet, analytical reports, and statistical compilations. However, it also involves the verification and consolidation of the available data. Finally, the methods of literature analysis and statistical analysis were applied (starting with the presentation of basic statistics and ending with selected methods of multivariate analysis).
Findings: The demographic structure of IPSA holders is changing. There is a relative increase in the number of older people and a decrease in the number of younger people aged up to 30 and between 31 and 40. As saving up should start at the age of 20-25, the above phenomenon should be considered as worrying. IPSAs do not fulfil their role. There are various reasons for this: an ageing population, lack of awareness of the need to save for the old age, and incentives for saving up with IPSAs losing their function due to changes in tax law.
Research limitations/implications: A limitation of the research conducted was the structure of the available data. Cross-sections of the age of the insured were only available in terms of the number of active IPSAs. There is no publicly available data of this type, but in terms of the value of the accumulated capital, the number of accounts into which payments were made, the average amount of payments or the number of one-off or instalment withdrawals. The inclusion of the aforementioned data could broaden the basis for conclusions on the state of the pension insurance market.
Originality/value: Admittedly, the study of the demographic structure of the Polish population in the context of the demand for pension products appears in literature from time to time, but such studies are few. What is new here is the presentation and analysis of the current data (as of the end of 2023) and, above all, the application of multivariate data analysis to the subject of the study. The article is addressed to researchers dealing with the social insurance system, in particular pension insurance.

Keywords: social insurance, pension insurance, demographic structure, multidimensional scaling.
Category of the paper: research paper, conceptual paper.

1. Introduction

In 1999, a fundamental reform of the pension system was introduced in Poland. The previous pay-as-you-go model was replaced with a mixed pay-as-you-go and funded model. Since then, we have begun to speak of pillars of the pension system in Poland. The first of these is the reformed Social Insurance Institution (SII; Polish: ZUS) and the second one is the Open Pension Funds (OPF; Polish: OFE). In addition to these two pillars, there is also a third pillar, to which different authors include various types of voluntary pension security schemes. The ones most frequently referred to include: Employee Pension Schemes (EPP; Polish: PPE), Individual Pension Accounts (IPA; Polish: IKE), Individual Pension Security Accounts (IPSA; Polish: IKZE), and Employee Capital Plans (ECP; Polish: PPK).

The first pillar is a mandatory public system, managed by the SII. It is, as before, a pay-as-you-go type of scheme, with the difference that the defined benefit system has been replaced with a defined contribution system. This means that, although part of the contribution going into the first pillar is still allocated to the payment of current pensions, the SII "records" how much each person has accumulated over the years of work in their "virtual" account. This way, the working life period and earnings have been linked to the amount of the pension. The amount of the pension benefit that will be paid from the first pillar corresponds to the amount of pension capital paid in divided by the life expectancy of the person in retirement. This encourages longer working lives.

The reform modification implemented in 2014 significantly reduced the role of OPFs. (Jamróz, Lisowski, 2017). Various proposals for further changes to the pension system have been put forward since 2017. One of these is a project for the complete abolition of OPFs. Among other things, it is proposed that 75% of the remaining funds in OPFs should go to IPSAs. Although they are less popular than OPFs, they are similar to them in terms of the tax preferences applied (in both cases, it is a deduction from income).

IPSAs have been functioning in the Polish social insurance system since 2012. Since their introduction, they have been an extension of the third pillar of the system, i.e. voluntary saving for the future retirement. There are currently four incentives for setting up an IPSA:

- The possibility to deduct the amounts contributed to IPSA from income (upon annual tax return filing).
- Exemption of the profits generated by these savings from income tax on capital gains (the so-called Belka tax).

- Exemption from inheritance and gift tax.
- Welcome payment and annual subsidies from the state budget.

Regarding the first point, it should be added that contributions to IPSA, and therefore deductions, cannot exceed a set limit.

An IPSA is therefore one form of saving for the old age. At the same time, changes have been made to the tax system in Poland, in particular to the Personal Income Tax Act. The lowering of the first tax threshold and a significant increase in the amount of tax-exempt income undoubtedly had an adverse effect on the IPSA market. One of the primary advantages of an IPSA, which is the deduction of contributions from income, has lost much of its attractiveness. On the other hand, awareness of the need to save for the old age is not growing in Poland. The increasing life expectancy and the ageing of the population can also be observed. In this situation, it seems interesting to take a look at the demographic changes taking place in the IPSA market in Poland.

2. Methods

As mentioned earlier, the *desk research* method was used, among others. The primary data source was the FSA website (https://www.knf.gov.pl/dane_i_opracowania). A total of 23 semi-annual reports on the state of the IPSA market (December 2012 – December 2023) were collected. The data included the number of policies by age group, separately for women and separately for men (KNF, 2024). The age ranges were as follows:

- up to 30,
- 31-40,
- 41-50,
- 51-60,
- 61-65,
- over 65.

IPSAs can be operated by 5 types of entities:

- insurance companies,
- Investment Fund Companies (IFCs; Polish: TFI),
- entities conducting brokerage activity,
- banks,
- Public Pension Fund Companies (PPFCs; Polish: PTE; as voluntary pension funds – VPFs; Polish: DFE).

The demographic structure of IPSA holders was presented first. This structure was then transformed into a set of 60 variables for further analysis. The calculated simple Pearson linear correlations show a number of significant relationships between the variables, with both directly proportional and inversely proportional relationships. However, the correlation matrix (60x60) does not provide basis for generalised conclusions. Significant linear correlation coefficients only indicate that some kind of a relationship exists between the variables, but the direction of the causal relationship cannot be determined based on them. It cannot even be ruled out that the relationship is random. In order to verify this, it would be necessary, for instance, to examine causality according to Granger (Granger, 1969) for each pair of variables. Instead of the aforementioned method, multidimensional scaling was used.

Multidimensional Scaling (MDS*)* can be an alternative to factor analysis. In general, the goal of the analysis is to detect meaningful underlying dimensions that allow the researcher to explain observed similarities or dissimilarities (distances) between the investigated objects. In factor analysis, the similarities between objects (e.g. variables) are expressed in the correlation matrix. With MDS, analysis of any kind of similarity or dissimilarity matrix, in addition to correlation matrices is possible.

3. Results

As it appears from Table 1 (Appendix), the age structure of IPSA participants is changing. As far as women are concerned, the share is decreasing in the case of those aged up to 30 (from 8.4 to 1.6%), from 31 to 40 (from 13.6 to 8.2%), and from 41 to 50 (from 15 to 12.1%). After period of growth between 2012 and 2016, the proportion of people aged 51 to 60 has also been decreasing from 2017 onwards (from 15.8 to 13.1%). However, the proportion of people of retirement age is increasing (from a total of 0.4 to as much as 12.7%).

As far as men are concerned, the changes in the age structure look different. While the share of those aged up to 30 has fallen sharply (from 11.6 to 3.0%), the share of those aged between 31 and 40 has changed only slightly (initially falling from 13.7 to 11.7% and then rising to 12.7%). For the 41-50 age range, a slow increase can be observed (from 12 to 14.3%). For the 51-60 range, virtually no fluctuation is observed (11.9% on average). Finally, for the 61 to 65 bracket, there is an increase (from 0.6 to 6.2%), and then, from 2019 onwards, a decrease (from 6.2 to 5.4%). As with women, we can see an increase (from 0.1 to 5.2%) for those over 65.

Figures 1 and 2 (Appendix) show the development of the number of IPSAs by age group. When comparing the number of accounts at the beginning of the study period (December 2012) with the number of accounts at the end of the period (December 2023), it can be seen that it has not changed significantly. This is the case for most age groups. The total number of IPSAs

among women also changed only slightly, falling from 252,000 to 246,000 over the aforementioned period. Among men, in turn, the number of IPSAs increased slightly from 245,000 to 269,000. It should be noted at this point that the significant decrease in the number of IPSAs in all age groups, visible in Figures 1 and 2, which occurred between 2019 and 2020, was due to the closure of accounts that were not funded by contributions (KNF, 2024).

Other information is provided by the cross-sections taking into account the institution (and therefore the form) in which IPSAs are operated. As already mentioned, IPSAs can take 5 forms. As it appears from Figures 3 and 4 (Appendix), the popularity of the different forms of IPSAs has varied for both men and women. Between 2012 and 2019, the largest number of accounts were operated by insurance companies. At the same time, accounts operated by IFCs became more significant. As already mentioned, in the years 2019-2020, accounts to which no contribution was made were closed. Charts 3 and 4 indicate that insurance companies have been affected the most by this closing of accounts. At the end of June 2019, the total number of IPSAs operated by insurance companies was 445,500, and only 96,400 a year and a half later. Since then, the largest number of IPSAs have been operated by IFCs and, as can be seen, their advantage over other forms has been growing. Moreover, the number of accounts operated in a different form than by IFCs has remained stable since 2020 (with the exception of men with IPSAs operated by brokerage entities).

The data collected makes it possible for various summaries and cross-sections to be created. However, in order to capture different relationships than previously found, a multidimensional scaling method was used. Figure 5 shows a two-dimensional scatter plot in a reconstructed space. Several groups of variables are clearly visible. The 3 most relevant groups are marked. There are 10 variables that belong to group 1, eight of them summatively represent accounts operated for people up to 60 years of age in the form of VPFs, and the other two correspond to accounts for people under 30 years of age operated by insurance companies. Group 2 includes eight variables relating exclusively to accounts operated by insurance companies for people aged between 30 and 60. Finally, the most numerous group 3 comprises 34 different variables, including, which is worth noting, a set of six variables representing accounts operated by brokerage entities. The remaining 10 variables were not included in any of the selected groups. The formation of three groups indicates a significantly different development of demand for IPSAs depending on the age and gender of the insured and depending on the form of the account (organisational form). In order to interpret the results obtained, an attempt should be made to identify the two dimensions of multidimensional scaling. Additional calculations indicate that dimension one reflects the sum of Pearson linear correlation coefficients *(r)* between the given variable and the other 59 variables. Negative values on the X-axis therefore indicate a preponderance of negative correlations, i.e. inversely proportional relationships between the variables. Conversely, positive values on the X-axis show a preponderance of directly proportional relationships between the variables, i.e. collinearity between the variables. It was somewhat more difficult to interpret the significance of dimension two. Ultimately,

it can be surmised that the positive values of the vertical coordinate indicate the preponderance of relative increases in the number of accounts for the given demographic group. Figure 5 shows that variables K61_65_ZU and M61_65_ZU have the highest vertical coordinate value. The data indicates that the numbers of IPSAs operated by insurance companies for people between 61 and 65 years of age show an increase for most six-month periods. However, variable M41_50_DFE has the lowest vertical coordinate. The number of IPSAs operated in the form of VPFs for men between 41 and 50 years of age showed a decrease for almost half of the half-year periods under study.

4. Discussion

One of the fundamental social problems is pension security, or old age security. The reform of the pension system mentioned above, which was introduced in 1999, was supposed to create completely new prospects for the insured by introducing a mixed pay-as-you-go and funded system. In particular for those born after 31 December 1968, who were obliged to opt for the OPF membership. After 1999, the system has been reformed several times, with voluntary forms of saving for the old age introduced in parallel. Among others, IPSAs were created, which are the subject of this study.

There has been a long-standing debate in literature on whether to save for the old age and for how long (from when). This, of course, depends on a number of factors, such as the existing pension system and the demographic situation, including: life expectancy, birth rate, replacement rate or the number of people working per pensioner. Other factors include: the level of household income, the state of the healthcare system, the level of inflation, the level of unemployment, and probably many others. Also of fundamental importance is the awareness of the need to save for the old age.

As far as Poland is concerned, the problem of the ageing population should be noted. Between 2012 and 2019, the average life expectancy of women increased from 80.98 to 81.75 years, and that of men also increased from 72.71 to 74.07 years. There were decreases in 2020 and 2021 (COVID-19 pandemic), but in 2022, the situation returned to normal and increases were recorded to 81.06 years for women and 73.42 years for men. According to an announcement of the Social Insurance Institution from March this year, in 2023, a person (there is no gender breakdown in the announcement) aged 60 had 22.02 years of life ahead of them, and a person aged 65 – 18.24 years. In other words, this is therefore the averaged projected period of retirement. As this time has increased, the pensions granted from April 2024 have been lower. According to the SII, the latest life expectancy table results in the pension of a person aged 60 being calculated as 3.7% lower and that of a person aged 65 as 4.1% lower than on the basis of the previous table (GUS, 2024). This corresponds to amounts lower by PLN 100-150.

The replacement rate, i.e. the ratio of the average pension received to the average salary received during working life, has also been changing unfavourably. At the beginning of the period under study, i.e. in 2012, the replacement rate was 60%. Within the next two years, it rose to 61.8% and has been declining since 2014. In 2020, the replacement rate was 42%. In 2022, the rate did increase to 54%, but this was the result of additional benefits and not a steady trend. According to forecasts, by 2060 the replacement rate could even fall to around 19%, assuming the current retirement age (ZUS, 2024).

The number of working people per pensioner is also decreasing. In 2010, it was 1.94; by 2023, it has fallen to 1.9.

The remarks made in the last two paragraphs, mainly apply to the pay-as-you-go system. In a funded system, contributions go into an individual account, so the replacement ratio, or the number of people working per pensioner, are of little importance.

In view of this state of affairs, the need for an additional voluntary pension security scheme seems natural. Unfortunately, this is not obvious in practice. Various studies have been carried out on this issue over the recent years. One of the latest is a study conducted in March 2024 by *Goldman Sachs TFI* (Goldman Sachs, 2024). According to this study:

- only slightly more than half of Poles (54%) are thinking about somehow securing their financial future with an additional pension,
- 21% of respondents think they will work for the rest of their lives,
- 25% rely only on benefits paid out by the state insurer,
- among those taking steps towards additional retirement security, saving is most preferred (49%), followed by investing (32%) and owning additional retirement products (31%),
- the most frequently mentioned methods of collecting funds for an additional retirement pension include a savings account (28%), a deposit (21%), and putting money "under the mattress" (18%),
- more than 60% of respondents are willing to put aside no more than PLN 500 per month for an additional pension,
- more than half of the respondents will be satisfied with an amount between PLN 1000 and PLN 3000 of additional pension. However, one in five aims at an additional monthly amount of PLN 4000,
- only one in three Poles is able to correctly decipher the Polish abbreviation for IPSA (IKZE),
- only 6% of Poles declare that they use an IPSA,
- 16% of self-employed persons declare that they have an IPSA,
- as many as 36% of IPSA holders choose not to use their allowance (deduction from income),

- only 3% of Poles use the IPSA tax relief, and among IPSA holders only 64% of respondents use it,
- only one in 10 Poles knows what the annual limits for IPSA contributions are,
- pension products are mainly held by men (37%) aged 40-49 (39%), people with higher education (38%), those running a business (44%), and those earning more than PLN 6,000 per month.

In the context of the above research, it is worth asking the question: When should one start saving? The Milken Institute, for instance, states that we should start saving for retirement at the age of 25. Moreover, it is necessary to put aside PLN 100 per week to accumulate more than PLN 1.1 million by the age of 65 (Milken Institute, 2024). Literature on saving points to time horizon as one of the most important determinants of saving behaviour (Lea, Webley, Walker, 1995; Rabinovich, Webley, 2007). Research also indicates that a further horizon is positively correlated with saving in general (Avery, Kennickell, 1991; Fisher, Montalto, 2010). A further planning horizon is also positively correlated with the goal of saving, which may be a higher pension (Białowąs, 2013).

Taking the above into account, it might be assumed that one should start saving for the future retirement at the age of 25-40 or even immediately after starting the first job.

Meanwhile, Polish statistics indicate this is not the case here. The demographic structure of IPSA holders does not seem to promise adequate pension security for many people.

5. Summary

According to the research carried out on IPSAs, the demographic structure of the holders is deteriorating from the point of view of public interest, which is the need to secure adequate social and living conditions for all socio-economic groups, particularly people of retirement age. The percentage of people aged up to 30 and between 31 and 40 (i.e. the age at which one should already be saving for the old age), both among women and men, has been steadily declining, and has been doing so since the introduction of IPSAs. These figures have fallen from 22 to 9.8% and from 25.3 to 15.7% respectively. Also, the multidimensional scaling procedure carried out indicates, in part, that the variables representing account holders aged up to 30 and those aged 31 to 40 have clustered in separate groups (groups 1 and 2) than the others. It should be mentioned here that this applies to accounts operated by insurance companies and accounts in the form of voluntary pension funds. These variables have the lowest negative horizontal coordinates, which indicates that they are different from most of the other variables clustered in group 3.

Thus, it can be concluded that IPSAs do not fulfil the tasks set for them. The reasons appear to be of various types.

Firstly, Polish society lacks sufficient awareness of the need to save for the old age and of the applicable tax law (deductions from income). Moreover, the new pension system has only been in place for 25 years and the IPSAs for just 12 years, so relatively few people receive an additional pension. Withdrawals made from IPSAs in 2023 (both in instalments and one-offs) amounted to less than PLN 162 million. Although as recently as 2020, it was around PLN 29 million. In comparison, the amounts paid out from the Social Insurance Fund (SIF; Polish: FUS) in 2023 are close to PLN 270 billion.

Secondly, Poles' incomes are simply too low, which does not allow them to save for the old age (this problem is only hinted at; it may be the subject of further research).

Thirdly, as far as IPSAs are concerned, this form of saving is no longer attractive. The introduction of a high tax-exempt amount of income (PLN 30,000), the reduction of the first tax rate (general, continuous progressive tax scale) to 12%, and raising the tax threshold to PLN 120,000 makes the perspective of deducting amounts paid into an IPSA from income, combined with the requirement to pay 10% tax in the future, hardly interesting. A reduction or abolition of the aforementioned tax has been called for, but so far it has remained in place. The benefit of exempting the IPSA funds from the "Belka tax" is not much of an incentive either. For instance, one of the largest Polish banks (ING Bank) offers the IPSA in the form of a deposit account bearing interest at 4% per annum. With inflation at 2.5% (as of June 2024), the real interest rate on the IPSA is only just 1.5%. Without much difficulty, one can find an offer of bank deposits with an interest rate of 5.5-6%. In addition, of course, the money paid into the IPSA is "frozen" until the age of 65. The current situation of IPSAs has improved anyway, because only a few months ago, interest rates on the accounts were lower and inflation was higher. This resulted in real interest rates being negative.

The last incentive to set up an IPSA is the exemption from inheritance and gift tax. But the act on inheritance and gift tax has been significantly liberalised in recent years. For instance, an unlimited tax exemption has been introduced for persons in the so-called "zero" tax group, i.e. members of the immediate family (spouse, descendants, ascendants, stepchildren, siblings, stepfather, stepmother). The only condition is the submission of a relevant tax form (IN-1).

References

1. Avery, R.B., Kennickell, A.B. (1991). Household saving in the U.S. *Review of Income and Wealth, No. 37(4)*, pp. 409-430.
2. Białowąs, S. (2013). *Zachowania oszczędnościowe w polskich gospodarstwach domowych – postawy, determinanty, modele*. Poznań: Wydawnictwo Uniwersytetu Ekonomicznego w Poznaniu, p. 74.

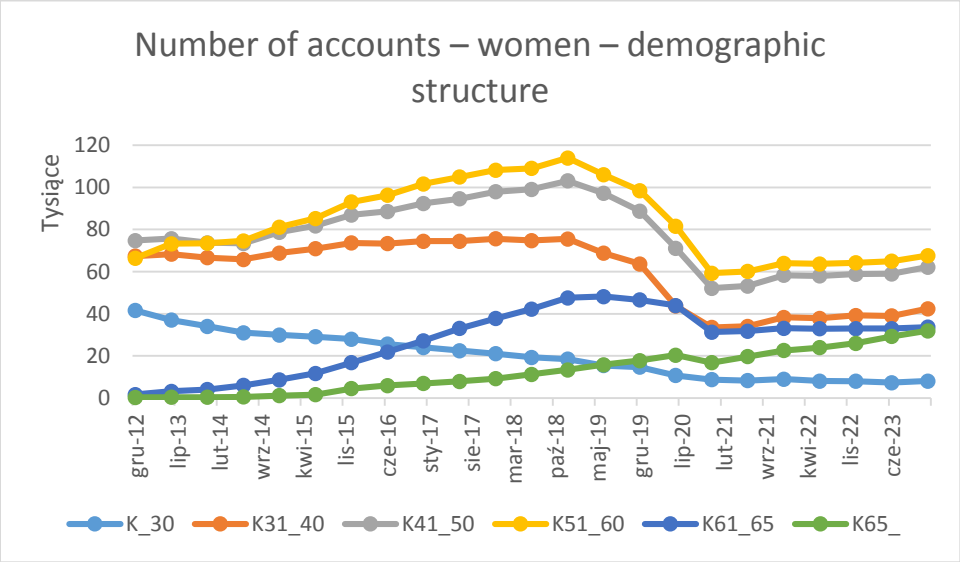
3. Cloud Software Group, Inc. (2023). *Data Science Workbench*, *version 14*. Retrieved from: http://tibco.com.
4. Fisher, P.J., Montalto, C.P. (2010). Eff ect of Saving Motives and Horizon on Saving Behaviors. *Journal of Economic Psychology, No. 31*, pp. 92-105.
5. Główny Urząd Statystyczny (Central Statistical Office). Retrieved from: https://stat.gov.pl/obszary-tematyczne/ludnosc/trwanie-zycia/, 17.07.2024.
6. Goldman Sachs TFI. *Dodatkowa emerytura i ulga z tytułu IKZE.* Retrieved from: https://www.gstfi.pl, 19.07.2024.
7. Granger, C.W.J. (1969). Investigating Causal Relations by Econometric Models and Cross-spectral Methods. *Econometrica*, *37(3)*, pp. 424-438, doi: 10.2307/1912791, JSTOR: 1912791.
8. Jamróz, A., Lisowski, R. (2017). Tax preferences vs. development of IKZE in Poland. *Research Papers of Wrocław University of Economics, no. 488,* pp. 88-98. ISSN 1899-3192; ISBN: 978-83-7695-684-8, doi: 10.15611/pn.2017.488.08.
9. Komisja Nadzoru Finansowego (KNF; Polish Financial Supervision Authority). *Informacja o stanie rynku emerytalnego w Polsce na koniec 2020 r.* Retrieved from: https://www.knf.gov.pl/dane_i_opracowania, 6.07.2024.
10. Lea, S.E.G., Webley, P., Walker, C.M. (1995). Psychological factors in consumer debt: Money management, economic socialization, and credit use. *Journal of Economic Psychology, No. 16*, pp. 681-701.
11. *Milken Institute*. Retrieved from: https://milkeninstitute.org, 19.07.2024.
12. Polish Financial Supervision Authority (KNF). Retrieved from: https://www.knf.gov.pl/dane_i_opracowania, 28.06.2024.
13. Rabinovich, A. Webley, P. (2007). Filling the gap between planning and doing: Psychological factors involved in the successful implementation of saving intention. *Journal of Economic Psychology, No. 28*, pp. 444-461.
14. Raport ZUS: *sytuacja FUS jest stabilna*. Zakład Ubezpieczeń Społecznych (Polish Social Insurance Institution). (2024). Retrieved from: https://www.zus.pl/-/raport-zus-sytuacja-fus-jest-stabilna, 18.07.2024.

Appendix

Table 1.
Demographic structure of people with an IPSA (%)

Structure	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Women aged:	**50.7**	**50.8**	**50.9**	**50.7**	**50.8**	**50.7**	**50.9**	**50.4**	**49.5**	**49.3**	**48.2**	**47.8**
up to 30	8.4	6.9	5.7	4.7	3.7	3.1	2.5	2.2	2.2	2.0	1.7	1.6
31-40	13.6	13.4	13.0	12.3	11.6	11.0	10.3	9.7	8.2	8.1	8.2	8.2
41-50	15.0	14.8	14.9	14.5	14.4	14.2	14.1	13.6	12.8	12.7	12.4	12.1
51-60	13.4	14.8	15.4	15.6	15.8	15.7	15.6	15.0	14.5	14.3	13.5	13.1
61-65	0.3	0.8	1.7	2.8	4.2	5.5	6.5	7.1	7.7	7.6	6.9	6.5
over 65	0.1	0.1	0.2	0.8	1.1	1.3	1.8	2.7	4.1	4.7	5.5	6.2
Men aged:	**49.3**	**49.2**	**49.1**	**49.3**	**49.2**	49.3	49.1	49.6	50.5	50.7	51.8	52.2
up to 30	11.6	9.7	8.1	6.8	5.6	4.7	3.8	3.4	3.7	3.4	3.1	3.0
31-40 years old	13.7	14.3	14.2	14.0	13.5	13.2	12.7	12.8	11.7	11.7	12.5	12.7
41-50 years old	12.0	12.0	12.4	12.5	12.6	12.8	13.0	13.2	13.3	13.5	14.1	14.3
51-60	11.2	11.7	12.1	12.2	12.3	12.2	12.1	11.8	11.9	11.8	11.7	11.7
61-65	0.7	1.3	2.1	3.1	4.1	5.0	5.6	5.8	6.2	6.1	5.7	5.4
over 65	0.1	0.1	0.3	0.7	1.1	1.4	2.0	2.6	3.7	4.1	4.7	5.2

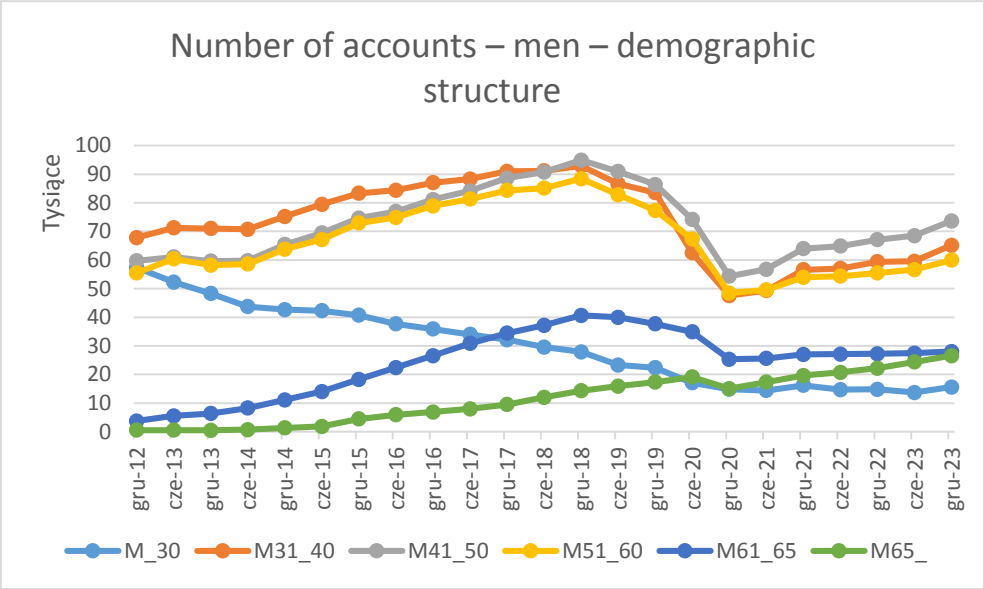
Source: author's own elaboration based on FSA data.



Note: K_30 – up to 30 years of age, K31_40 – 31-40 years of age, K41_50 – 41-50 years of age, K51_60 – 51-60 years of age, K61_65 – 61-50 years of age, K65_ – over 65 years of age.

Figure 1. Number of IPSAs in the years 2012-2023 – women.

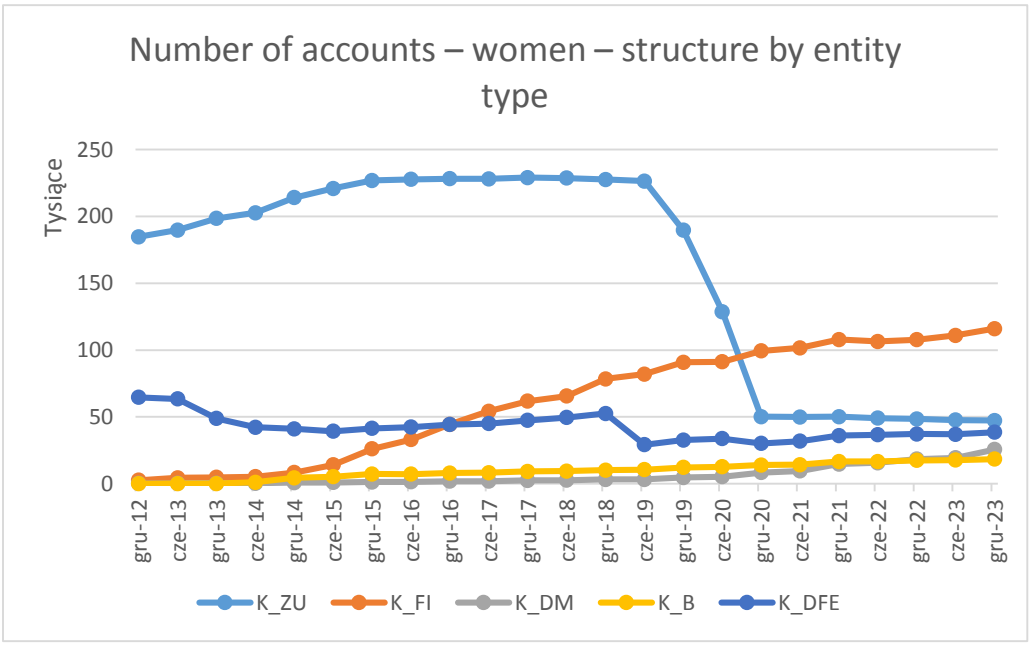
Source: author's own elaboration.



Note: M_30 – up to 30 years of age, M31_40 – 31-40 years of age, M41_50 – 41-50 years of age, M51_60 – 51-60 years of age, M61_65 – 61-50 years of age, M65_ – over 65 years of age.

Figure 2. Number of IPSAs in the years 2012-2023 – men.

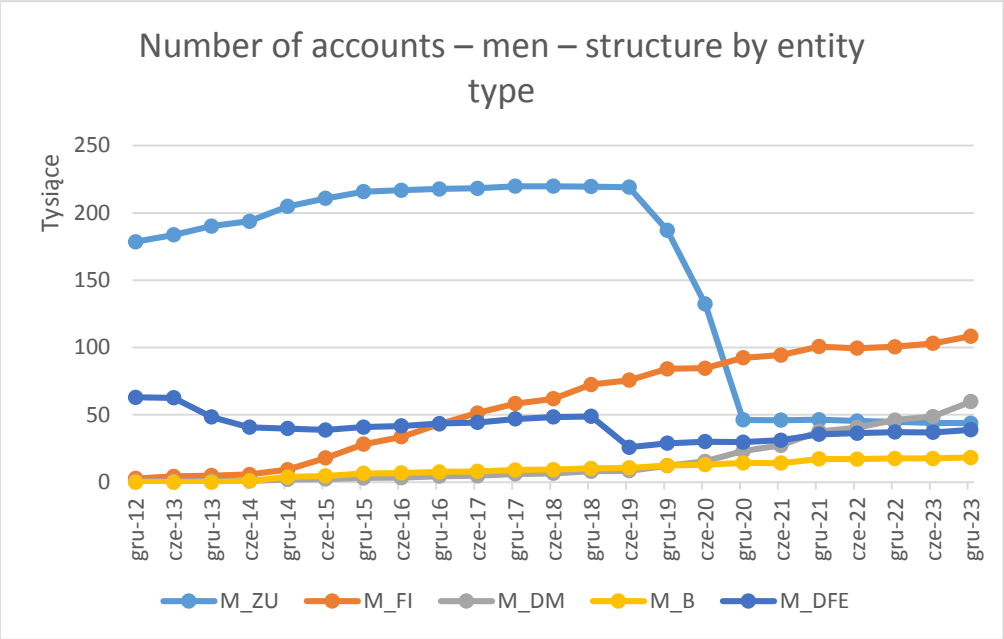
Source: author's own elaboration.



Note: K_ZU – insurance companies, K_FI – investment funds, K_DM – brokerage houses, K_B – banks, K_DFE – voluntary pension funds.

Figure 3. Number of IPSAs in the years 2012-2023 operated by different institutions – women.

Source: author's own elaboration.



Note: M_ZU – insurance companies, M_FI – investment funds, M_DM – brokerage houses, M_B – banks, M_DFE – voluntary pension funds.

Figure 4. Number of IPSAs in the years 2012-2023 operated by different institutions – men.

Source: author's own elaboration.

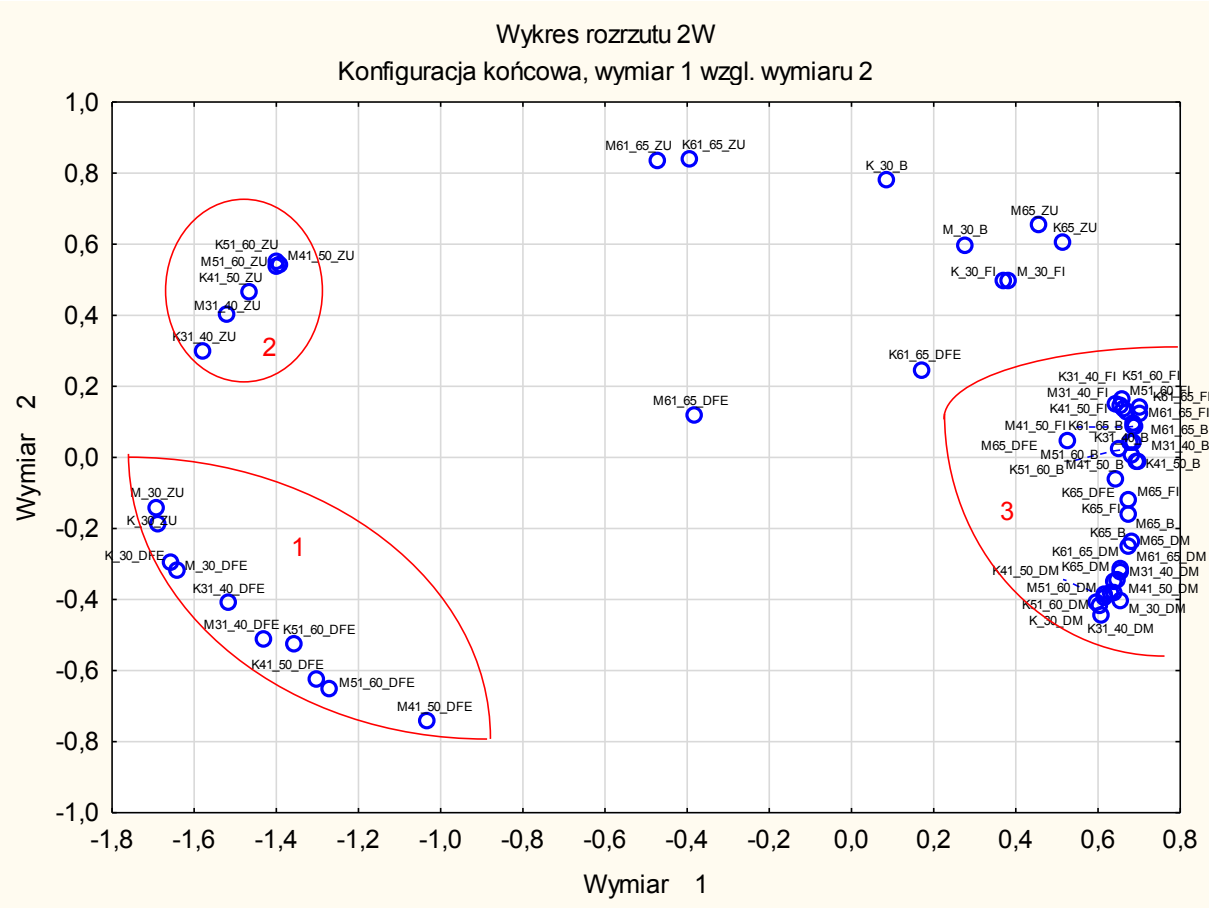


Figure 5. Multidimensional scaling.

Source: author's own elaboration with the use of *Statistica 14*.

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A STUDY ON THE DISTANCES BETWEEN POLAND AND SELECTED EUROPEAN COUNTRIES AND THE PROVINCES OF POLAND WITH RESPECT TO THE USE OF NEW TECHNOLOGIES BY ENTERPRISES

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Purpose: The aim of the analysis was to examine the dynamics of change in the synthetic variables describing the level of the phenomenon under consideration in selected European countries and Polish provinces.
Design/methodology/approach: The study examines the use of the Internet and information and communication technologies by enterprises in the Polish provinces and selected European countries. Data were drawn from Statistics Poland and Eurostat, taking into account the thematic area of the study and data availability. The study of distances led to the identification of the areas in the development and use of new technologies where Poland differed from other countries and the Śląskie province differed from other provinces. The analysis of the European countries covered three thematic areas in the years 2013-2020, and the analysis of provinces - two thematic areas in the years 2020-2022.
Findings: The study examines the use of the Internet and information and communication technologies by enterprises in the Polish provinces and selected European countries. Taxonomic analysis is an effective tool for assessing the influence of factors on selected characteristics of the development of the studied phenomenon.
Research limitations/implications: The inability to create a set of comparable statistical data over many years is the main limitation of the analysis.
Originality/value: The presented taxonomic analysis of the phenomenon under consideration can be used to compare different objects (countries, provinces, municipalities) or to carry out comparative analysis of other aspects of the issue, and the results of these studies will contribute to further research in this area. The results of the proposed research methodology can be used in economic and socio-economic policy analyses.
Keywords: taxonomic methods, Internet and ICT usage, COVID-19.
Category of the paper: Research paper.

1. Introduction

The ongoing digital revolution permeates all areas of our lives. Digital technology accompanies us every day (Drelichowski, 2002). We experience it in technological advancements, in particular through the Internet of Things or Big Data. Digital solutions assist us in our visits to public administration units, healthcare facilities, etc. – we are able to access their services remotely, submit applications and online forms. Increasingly, we take advantage of online shopping opportunities. We use mobile devices with internet access to attend to a variety of matters without leaving our homes, e.g. mobile banking applications enable us to make fast payments and transfers, etc.

Big data analytics tools allow automation of various processes, which results in cost reduction or production optimization. Digitalization is both an opportunity for development and a competitive weapon. Companies and organizations that implement modern solutions to enhance customer convenience can acquire a bigger number of customers or investors.

However, it should be remembered that the key to development is the ability to adapt to changes in business environments. This is the lesson learned from the Covid-19 pandemics as well as the war in Ukraine. Organizations can survive by investing in digital solutions, new tools, employee development, etc.

The aim of the analysis was to examine the dynamics of change in the synthetic variables describing the level of the phenomenon under consideration in selected European countries and Polish provinces. The study of distances led to the identification of the areas in the development and use of new technologies where Poland differed from other countries and the Śląskie province differed from other provinces.

2. The set of diagnostic characteristics of the problems under study

The study examines the use of the Internet and information and communication technologies by enterprises in the Polish provinces and selected European countries. Data were drawn from Statistics Poland and Eurostat. The dataset includes the scope of the study and the availability of data. The diagnostic variables adopted in the present study are measurable and best describe the development of the analysed phenomenon. Based on the calculated values of the coefficients of variation and the results of verifying correlation analysis conducted by means of an inverted correlation matrix, the final set of diagnostic characteristics which describes the phenomenon was obtained (Młodak, 2006; Chomątowski, Sokołowski, 1978; Pociecha et al., 1988; Panek, 2009; Zeliaś, 2004; Strahl, 1990; Malina, 2008).

Due to the lack of statistical data, it was necessary to reduce the thematic scope of the dataset. The analysis using selected data is a continuation of previous research (in the description of the data are used: S - stimulant) (Mika, 1995).

The Polish provinces (2020, 2021, 2022).

The first thematic area - variables related to access to the Internet by enterprises:

x_1 – Number of enterprises with broadband Internet access – [%] (S),

x_2 – Number of enterprises with access to the Internet via DSL or other – [%] (S),

x_3 – Number of enterprises, additional equipment in a mobile device to the Internet (e.g. notebooks, netbooks, tablets, smartphones) [%] (S),

x_4 – Number of employees of enterprises with remote access to business applications, documents, computer programs [%] (S),

x_5 – Number of employees in enterprises with remote access to business e-mail [%] (S).

The second thematic area - variables related to enterprises with Internet access buying cloud services:

y_1 – Number of Internet-enabled enterprises buying cloud services by type of email access – [%] (S),

y_2 – Number of enterprises with Internet access buying cloud services – office software (e.g. spreadsheet, word processor) – [%] (S),

y_3 – Number of enterprises with Internet access buying cloud services – financial and accounting software [%] (S),

y_4 – Number of enterprises with Internet access buying cloud services – enterprise database hosting [%] (S),

y_5 – Number of Internet-enabled enterprises buying cloud services – file storage[%] (S).

In describing the variables, the determination S – stimulant was introduced (Mika, 1995).

In 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020 the following set of variables was adopted for selected countries:

a) the first thematic area:
   z_1 – Number of enterprises having received orders online – [%] of enterprises (S),
   z_2 – E-banking and e-commerce [%] (S),
   z_3 – E-government activities of individuals via websites [%] (S).
b) the second thematic area:
   z_4 – Share of enterprises' turnover on e-commerce – [%] (S),
   z_5 – Percentage of the ICT sector on GDP [%] (S),
   z_6 – Digital single market – promoting e-commerce for individuals [%] (S),
   z_7 – High-tech exports [%] (S),
   z_8 – High-tech trade by high-tech group of products in million euro (S),
c) the third thematic area:
   z_9 – Population on 1 January (S),
   z_{10} – Number of individuals using the internet for selling goods or services [%] (S),
   z_{11} – Individuals using the internet for interacting with public authorities [%] (S).

3. Measuring distances between Poland and selected EU countries and the polish provinces with respect to the level of the phenomenon under study

The analysis of the level of ICT usage in enterprises was extended by examining distances between Poland and selected European countries. The differences between the values of variables representing the selected groups of measures and the value of the synthetic variable were determined. Next, the average rate of distance change was calculated according to formula (Zeliaś, 2004):

$$D_{qi} = \frac{d_{qi8} - d_{qi1}}{3} \tag{1}$$

where:

$$d_{qit} = z_{qit} - z_{qt} \tag{2}$$

i = 1, …, 17 (16 provinces), t = 1, …, 8 (t = 1, 2, 3), q = 1, 2, 3 (q = 1, 2).

When calculating the distances, the differences between the values were taken into account. A positive value means that, in a given year, in terms of the synthetic variable under consideration, Poland has a lower position than the country it is compared to (Zeliaś, 2004). A negative value indicates Poland's higher position than that of the other European country under examination.

Based on the values of the synthetic variable we can perform a more detailed analysis for selected European countries, and next – for Polish provinces (Zeliaś, 2004):

a) If in the years 2013 and 2020 (2020, 2021) the position of Poland (the Śląskie province) was lower than that of the country (province) it was compared with then: D > 0 means the distance increased while D < 0 shows a decrease in the distance between Poland (the Śląskie province) and the country (province) it was compared with **[**description **00]**.
b) If in the years 2013 and 2020 (2020, 2021) the position of Poland (the Śląskie province) was higher than that of the country (province) it was compared with then: D > 0 means the distance decreased while D < 0 indicates Poland (the Śląskie province) moved even further away from the country (province) it was compared with **[**description **11]**.
c) If in the year 2013 (2020) the position of Poland (the Śląskie province) was lower, but in the year 2020 (2021) Poland ranked higher than the country (province) it was compared with, it means that, in the time under study, Poland (the Śląskie province) had the same position as the country it was compared with and next - achieved a higher result **[**description **01]**.
d) A situation contrary to the one discussed in item c) indicates that in the period under study a country (a province) was on a par with Poland (the Śląskie province) and next, it ranked higher **[**description **10]**.

The value of 0 means that the value of the synthetic variable for Poland was lower than for the given country, for the value of 1 it means that it was higher (Zeliaś, 2004).

4. The empirical example

Once the variables are normalized, we synthesize each of the selected groups of measures and calculate a synthetic variable. The analysis covered 17 countries (Belgium, Bulgaria, Czechia, Germany, Estonia, France, Italy, Latvia, Lithuania, Hungary, Malta, Austria, Poland, Romania, Slovenia, Slovakia, Finland), the time frame was 8 years (2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020) and the number of variables was 11. In the second stage of the study, the analysis covered the Polish provinces (16 provinces), the time interval covered the years 2020, 2021, 2022. The number of variables was 10. Then, taking into account the value of the synthetic variable, the average rate of change of distances was calculated. The table presents the results for European countries.

Table 1.
Distance change values for Poland and European countries for three groups of meters

Country	D_1	Description	D_2	Description	D_3	Description
Belgium	-0.0060	00	0.00623	00	0.00372	00
Bulgaria	-0.0050	11	-0.00037	11	0.01658	11
Czechia	0.0016	00	-0.00252	00	0.01048	11
Germany	0.0163	00	0.01977	00	0.00516	00
Estonia	0.0034	00	0.00622	00	-0.00257	11
France	0.0209	00	0.01310	00	0.02898	00
Italy	-0.0007	11	-0.00693	11	0.00764	00
Latvia	-0.0010	11	-0.00213	00	-0.01239	11
Lithuania	-0.0042	11	-0.00174	00	-0.00896	11
Hungary	0.0047	00	-0.00525	10	-0.00819	10
Malta	0.0142	00	-0.01619	00	-0.01034	11
Austria	0.0142	00	-0.00510	00	0.00652	11
Romania	-0.0087	11	-0.01047	11	0.00082	11
Slovenia	0.0044	11	0.00123	00	0.04204	01
Slovakia	0.0191	01	0.01194	00	-0.01643	11
Finland	0.0138	00	0.01695	00	0.001384	00

Source: based on own research (https://ec.europa.eu/eurostat).

For D_1 we can say that the distance compared to Poland decreased only for Belgium and Slovenia (D_1 - presents the first thematic scope).

For D2 distance decreased for: Czechia, Latvia, Lithuania, Malta, Austria. For D_3, these are the following countries: Bulgaria, Czechia, Austria, Romania. For the other countries, the distance increased in the analyzed time period.

In the next step of the analysis, D values were determined for the Polish provinces.

Table 2.
Distance change values for the Polish provinces and the Śląskie province for two groups of meters

Province	D_1	Description	D_2	Description
Dolnośląskie	0.00352	11	-0.00542	11
Kujawsko-pomorskie	0.00646	11	-0.00165	11
Lubelskie	0.00776	11	-0.00192	11
Lubuskie	0.00623	11	-0.00138	11
Łódzkie	0.00285	11	0.000035	11
Małopolskie	0.00230	11	-0.00518	11
Mazowiecki	0.01780	00	-0.02101	11
Opolskie	0.00375	11	-0.0027	11
Podkarpackie	0.00652	11	-0.00058	11
Podlaskie	0.00420	11	-0.00259	11
Pomorskie	0.00259	11	-0.00336	11
Świętokrzyskie	0.00409	11	-0.00333	11
Warmińsko-mazurskie	0.00224	11	-0.00276	11
Wielkopolskie	-0.00541	11	-0.00643	11
Zachodniopomorskie	0.00352	11	0.000897	11

Source: based on own research (https://stat.gov.pl/)

For D_1 we see that the distance between the Śląskie province and the Mazowieckie province has increased. The distance also increased for the Wielkopolskie province. In other provinces the Śląskie province has a better position but the distance has decreased.

For D_2: the Łódzkie province and the Zachodniopomorskie province have reduced the distance to Śląskie province.

5. Conclusion

The aim of the analysis was to examine the dynamics of change in the synthetic variables describing the level of the phenomenon under consideration in selected European countries and Polish provinces. The study of distances led to the identification of the areas in the development and use of new technologies where Poland differed from other countries and the Śląskie province differed from other provinces. The analysis of the European countries covered three thematic areas in the years 2013-2020, and the analysis of provinces - two thematic areas in the years 2020-2022.

The results obtained in the first thematic area show a growing distance between Poland and the selected European countries (except for Belgium, Slovenia and Slovakia - the distance between Poland and these countries shortened).

As regards the second thematic area, the gap between Poland and Czechia, Latvia, Lithuania, Malta, Austria narrowed, while the distance between Poland and the other countries became bigger.

In the third thematic area we can observe a significantly increasing distance between Poland and all the other countries except Bulgaria, Czechia, Austria, Romania. Based on the results of the analysis the conclusion can be drawn that Poland remains far behind most selected countries when it comes to the use and development of new technologies.

The second stage of the analysis focused on Polish provinces. As far as the first thematic area is concerned, the results show that in the years 2020, 2021, 2022 the gap between the Śląskie province and the other provinces narrowed, but the Śląskie province ranked higher than the other provinces. The distance between the Mazowieckie province and the Wielkopolskie province grew. The second thematic area: the Łódzkie province and the Zachodniopomorskie province have reduced the distance to the Śląskie province.

During the covid-19 pandemic, the Śląskie province did not have the same level of Internet use as the Mazowieckie and Wielkopolskie provinces. To sum up, it can be said that digital transformation has a significant impact on our environment, businesses, public administration, society and national economy.

The process and effects of digitalisation are affecting our behaviour, consumer behaviour. Based on the experience of recent years, organisations, businesses, society and the economy need to react quickly to the changing environment and implement appropriate, effective solutions to survive.

References

1. Chomątowski, S., Sokołowski, A. (1978). Taksonomia struktur. *Przegląd Statystyczny*, *Vol. 25, Iss. 2*, pp. 217-226.
2. Drelichowski, L. (2002). Społeczeństwo informacyjne a kształtowanie rozwoju zrównoważonego. *Promocje, No. 2*.
3. Grabiński, T., Wydymus, A., Zeliaś, A. (1989). *Metody taksonomii numerycznej w modelowaniu zjawisk społeczno-gospodarczych*. Warszawa: PWN, pp. 25-49.
4. https://ec.europa.eu/eurostat.
5. https://stat.gov.pl.
6. Malina, A. (2008). *Przestrzenno czasowa analiza rynku pracy w Polsce i krajach Unii Europejskiej*. Kraków: Wydawnictwo Uniwersytetu Ekonomicznego w Krakowie, pp. 215-280.
7. Mika, J. (1995). *Analiza statystyczna Polski na tle krajów Unii Europejskiej*. Katowice: Śląsk, pp. 10-25.
8. Młodak, A. (2006). *Analiza taksonomiczna w statystyce regionalnej*. Warszawa: Difin, pp. 25-66.

9. Panek, T. (2009). *Statystyczne metody wielowymiarowej analizy porównawczej*. Warszawa: Szkoła Główna Handlowa w Warszawie – Oficyna Wydawnicza, pp. 58-114.
10. Pociecha, J., Podolec, B., Sokołowski, A., Zając, K. (1988). *Metody taksonomiczne w badaniach społeczno-ekonomicznych*. Warszawa: PWN, pp. 20-90.
11. Strahl, D. (1990). *Metody programowania rozwoju społecznego-gospodarczego*. Warszawa: PWE, pp. 35-69.
12. Zeliaś, A. (2006). *Poziom życia w Polsce i krajach Unii Europejskiej*. Warszawa: PWE, pp. 195-212.

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ARCHITECTURAL DECISIONS SUPPORTING THE MANAGEMENT OF PUBLIC UTILITY BUILDINGS

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Purpose: The aim of the article is to present the concept of an integrated system for managing cultural institutions.
Design/methodology/approach: The analysis is based on the specification of requirements and making architectural decisions to support management.
Findings: Supporting the management of cultural institutions' activities.
Originality/value: A detailed specification of requirements has been proposed for the functioning of cultural institutions, and the development of mobile and web applications.
Keywords: cultural institution, software architecture, management.
Category of the paper: Research paper.

1. Introduction

There is no doubt that in recent times we have witnessed the digitization of various areas of our lives. The rapid advancement of technology has permeated every facet of our daily routines, from how we communicate and work to how we manage and interact with public services. However, these innovations do not always fully meet users' expectations. The discrepancy between technological potential and actual user satisfaction leads to the continuous search for new solutions that can bridge this gap effectively. Many social institutions currently operate with incomplete or inefficient applications and systems, which hinders their ability to fully harness the benefits of digitization. This paper presents the concept of anintegrated system

designed to support the management of public utility facilities, with a particular focus on cultural institutions.

Several areas of cultural institutions' operations were considered in this study, such as communication with the local community, the range of activities offered by the institutions, and integration with social media. Effective communication with the local community is paramount for cultural institutions to remain relevant and engaged with their audience. This includes promoting events, gathering feedback, and fostering a sense of community ownership and participation.

A detailed specification of requirements has been proposed to address these needs. This specification encompasses the technical, functional, and user experience aspects necessary for the successful implementation of the integrated system. After specifying the requirements, it was necessary to make architectural decisions that would align with the project's goals and constraints. The task set by the user is the simultaneous development of a mobile and web application.

2. Scope of the project

The functioning of cultural institutions encompasses three primary areas: communication, reservation, and system control. Each of these areas is integral to the efficient management and operation of such institutions, ensuring they can effectively engage with the public, manage their resources, and maintain smooth operational workflows.

Within the scope of communication, several functionalities must be considered to enhance the interaction between cultural institutions and their audience:

a) functionality that enables the publication of new information about planned activities,
b) the possibility of integrating the system with social media platforms such as Facebook and Instagram,
c) sending email notifications to users about news and changes in cultural institutions.

Within the reservation system, several aspects are critical for managing user interactions and participation in cultural activities:

a) sign-ups for activities offered by cultural institutions,
b) ticket reservations,
c) participation in events and activities.

System control is another critical area, involving the management of user profiles, permissions, reservations, and payment statuses.

As part of the conducted research aimed at understanding the current standards of cultural institutions, a survey among individuals interested in the functioning of cultural institutions was proposed.

Based on the conclusions drawn from the surveys, it was crucial to develop a flexible communication environment that meets the expectations of institutions operating in various settings. An interesting finding from the surveys is that traditional methods of information storage still dominate; besides computer databases, paper documentation remains prevalent. It is noted that online technologies will soon dominate, as they offer advantages in terms of efficiency, accessibility, and data security. This shift towards digitalization underscores the need for an integrated system that can seamlessly transition institutions from traditional to modern methods of information management.

The paper proposes a system that will significantly streamline the operations of cultural institutions. This system is designed to enhance communication, simplify reservation processes, and provide robust system control, thereby meeting the diverse needs of cultural institutions.

3. Choice of technology

A key issue is the choice of technology. It is proposed to develop both a mobile application and a web application. This dual-platform approach is essential for reaching users on their preferred devices, whether they are accessing the system from their smartphones or desktops.

The choice of backend technology was crucial. The backend was implemented using Kotlin (Jemerov, Isakova, 2018) and the Spring Boot framework (Walls, 2015). Kotlin was selected because it is designed to interoperate seamlessly with Java, offering modern language features while maintaining compatibility with existing Java libraries and frameworks. This interoperability ensures that the development team can leverage existing Java expertise and resources, while also benefiting from Kotlin's concise syntax and enhanced safety features, such as null safety and extension functions. The Spring Boot framework was chosen for its comprehensive suite of features that simplify the development of production-ready applications. Its dependency management capabilities, built-in transaction support, and extensive ecosystem of modules and extensions provide a robust foundation for building scalable and maintainable backend services.

For the visual component, TypeScript (Vanderkam, 2020) was chosen. TypeScript, a statically typed superset of JavaScript, has become increasingly popular and now dominates over 66% of projects (TypeScript, 2022). Its strong typing system helps catch errors early in the development process, enhancing code quality and maintainability. Additionally, the Angular Material library (Bampakos, Deeleman, 2023) was utilized to accelerate implementation. Angular Material provides a set of reusable, well-tested, and accessible UI components based on Google's Material Design specifications. This choice not only speeds up the development process by providing pre-built components but also ensures a consistent and user-friendly interface across the application.

The API specification was implemented according to the OpenAPI standard (Gough et al., 2020). The OpenAPI standard, formerly known as Swagger, provides a framework for defining and documenting APIs in a language-agnostic manner. This standardization facilitates the use of external code generation tools, which can automatically generate client libraries, server stubs, and API documentation from the API definition. This approach enhances the efficiency of development and integration processes, allowing for more seamless collaboration between frontend and backend teams and ensuring that the API remains well-documented and easy to use.

Currently, mobile application users predominantly use two operating systems, Android and iOS, which account for 99% of the market (TypeScript, 2022; Stasiewicz, 2013). Therefore, the project was based on these systems. For the mobile application development, technologies such as Kotlin Multiplatform Mobile (KMM) for Android and Swift for iOS were considered. However, to optimize development efforts and ensure a consistent user experience across both platforms, a cross-platform framework like Flutter or React Native could be utilized. These frameworks allow for the development of a single codebase that can run on both Android and iOS, significantly reducing development time and maintenance efforts while ensuring a native-like performance and user experience.

4. Software Architecture

Architectural decisions regarding the management support system for cultural institutions include several key elements (Gąbka et al., 2023):

1) Shared backend.
   To ensure simplicity of implementation and ease of maintenance, a monolithic backend architecture was chosen. This model eliminates the need for a complex microservices structure. A monolithic architecture allows for all the backend logic to be contained within a single codebase, simplifying the development and deployment processes. This approach reduces the overhead associated with managing numerous microservices, such as network latency, service discovery, and inter-service communication complexities.
2) Shared relational database.
   The use of a single relational database is crucial for effective data management. This approach facilitates the maintenance of information consistency and enables efficient query processing. Relational databases, such as MySQL, are well-suited for handling structured data and supporting complex queries, transactions, and relationships between data entities. The relational model provides robust support for data integrity and consistency through features like foreign keys and constraints.

3) Storing photos in the file system.
   To optimize the transfer and retrieval of large files, it was decided to store photos for mobile and web clients in the file system. This allows for resource savings in the database, focusing on storing essential information for business functionality. Storing large media files directly in the database can lead to performance bottlenecks and increased storage costs. By using the file system for these files, the system can leverage the file system's inherent efficiency in handling large binary objects. This approach also simplifies backup and recovery processes and can make scaling storage more straightforward.
4) Architecture visualization.
   The model developed by Simon Brown (Brown, 2017) moves away from VML in favor of a less formal method of visualizing architecture. This architecture visualization model proposes representing the architecture in four levels. The following levels are distinguished (Sokół, 2023):
   a) System Context Diagram.
      The The goal here is to present the operating environment of the system. The System Context Diagram provides a high-level overview of how the system interacts with external entities, such as users, external systems, and other stakeholders. This diagram helps stakeholders understand the boundaries and interfaces of the system, highlighting how it fits within the larger ecosystem.
   b) Container diagram.
      Separate containers that are part of the system are shown here. The Container Diagram breaks down the system into its major components or "containers", each responsible for a specific part of the application's functionality. These containers could represent web applications, mobile apps, databases, and external services. This level of detail helps in understanding the modular architecture of the system, facilitating easier management and scaling of individual components. It also aids in identifying how different parts of the system communicate and depend on each other.
   c) Component diagram.
      The Component Diagram delves deeper into each container, detailing the internal components and their interactions. This level of visualization is crucial for developers as it outlines the specific classes, modules, or services within a container and how they collaborate to fulfill the container's responsibilities. By providing a detailed view of the internal structure, the Component Diagram facilitates better design and implementation practices, ensuring that each component is well-defined and that their interactions are clearly understood.

d) Code.

Finally, a class diagram representing the code is created. This can be a UML class diagram. The Code level provides the most detailed view, illustrating the actual classes, methods, and their relationships within the codebase. This diagram is essential for developers during the implementation phase, as it ensures that the architectural design is accurately translated into the actual code.

Figure 1 shows one of the ways to visualize architecture based on a container diagram.

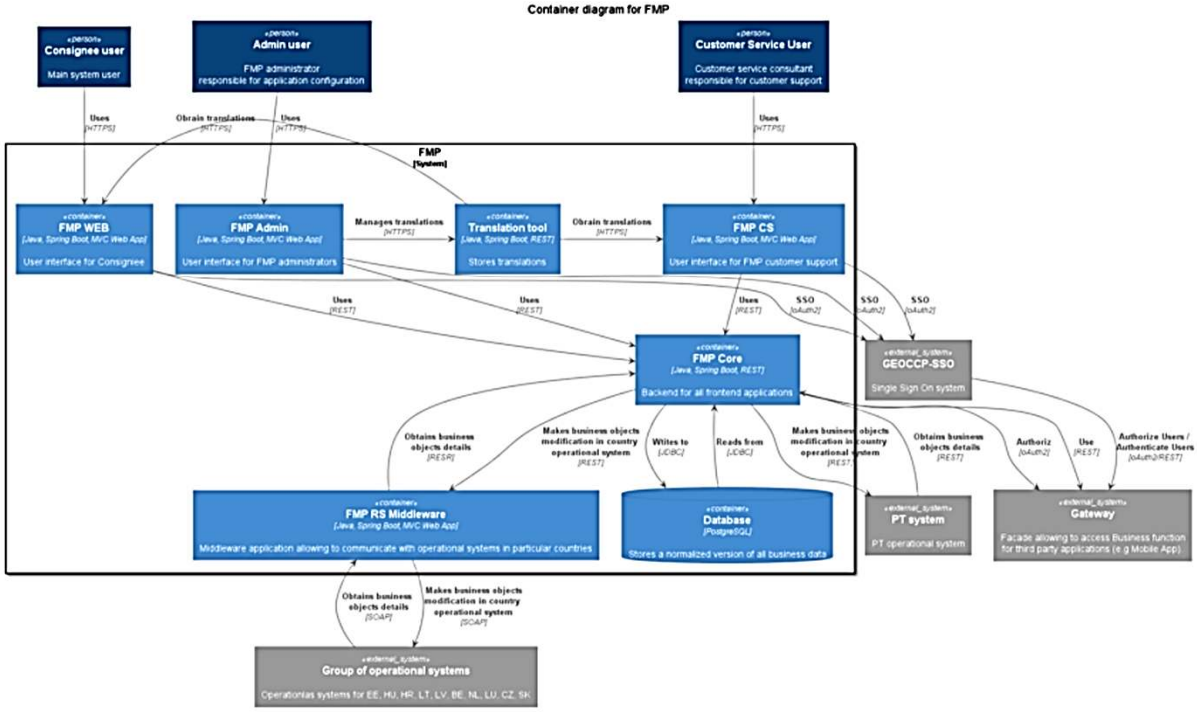

Figure 1. Container diagram of architecture visualization.

Source: Sokół, 2023.

5. Database system selection

The selection of a database system is a critical component in the architecture of any information system, particularly for managing public utility buildings. For this project, the MySQL database system was chosen (Lis, 2005) as the foundation of the data infrastructure. The selection of MySQL is justified due to several compelling factors: its flexibility, high performance, open-source nature, and widespread familiarity among database designers and developers.

The database was meticulously designed to manage various types of information integral to the operations of cultural institutions. These include user profiles, details of activities and events, announcements, institutional data, and integration points with social media platforms like Facebook. Ensuring data durability was a paramount concern, meaning that information

remains available and consistent across all devices, irrespective of where they are accessed. This durability guarantees that all users have access to the latest data, thus maintaining the integrity and reliability of the system.

As part of the database structure selection, A relational architecture was chosen for the database structure due to its proven efficiency in handling complex queries and ensuring data consistency. Relational databases, with their structured schema and support for SQL, are particularly adept at managing intricate relationships between different data entities.

The second critical aspect of the relational database choice is data consistency. Applying the Atomicity-Consistency-Isolation-Durability (ACID) principles in the MySQL database ensures that all transactional operations are safe, consistent, and durable. Atomicity guarantees that each transaction is treated as a single unit, which either fully completes or fully fails, ensuring no partial updates occur. Consistency ensures that the database remains in a valid state before and after the transaction. Isolation ensures that concurrent transactions do not interfere with each other, maintaining data integrity. Durability guarantees that once a transaction is committed, it remains so, even in the case of a system failure.

To effectively represent the data structures, detailed diagrams depicting the tables and their relationships were created. These diagrams illustrate the entities and their connections, providing a clear and organized view of the database schema. This work, as presented by Mazur H. and Mazur Z. (2020), ensures that all entities are properly defined and interlinked, facilitating efficient data retrieval and manipulation. These diagrams serve as a blueprint for the database, guiding the development and maintenance of the system.

6. Interaction with the Meta API

The Meta environment (Meta, 2023) was chosen as the social media platform for system integration. The system allows for the automatic creation of content on Facebook and Instagram, corresponding to posts created in the application. To achieve this, the Meta API was used.

The Meta API is based on the GraphOL standard (Lembo et al., 2022). This is a query language developed by Facebook that allows for precise specification of what data should be retrieved in each query. GraphOL enables dynamic determination of the structure of returned data, which reduces network traffic between the system and Meta services. By allowing developers to specify the exact data needed, GraphOL minimizes unnecessary data transfer and optimizes the performance of the application. This precision in data retrieval is crucial for maintaining the efficiency and responsiveness of the integrated system.

The first step of integration is registering a new application in the Meta developer panel (Developer, 2023). Along with the existing application in the developer panel, the Facebook Login procedure (Facebook, 2023) was used to generate tokens. Appropriate permission scopes were specified when generating the tokens. This data allows the initial goal to be fully achieved.

After generating the data required for verification, the post generation stage can begin. This process involves creating posts on the Facebook platform. The system automatically generates content based on predefined templates and user inputs, ensuring that the posts are consistent and aligned with the institution's branding and messaging guidelines. Similarly, updating content on Facebook is done by deleting the old post and creating a new one, according to the presented algorithm. This approach ensures that the latest information is always available to the audience, and outdated content is efficiently removed to prevent confusion.

7. Summary

In the area of communication, the system we introduced, which enables the publication of information related to the activities of cultural institutions, was highly rated by users. This functionality was effectively implemented, contributing to efficient communication between the cultural institution and its local community. Users appreciated the timely updates and the seamless integration with social media platforms like Facebook and Instagram, which significantly enhanced the visibility and reach of the institutions' activities. The system's ability to send email notifications further ensured that users remained informed about upcoming events and any changes, fostering a more engaged and informed community.

In the area of reservations, all necessary functionalities were properly introduced. The reservation system was designed to handle a variety of needs, including sign-ups for activities, ticket reservations, and participation in events. The ease of use and reliability of the reservation system received positive feedback from users. The system's intuitive interface allowed users to make reservations quickly and efficiently, reducing the administrative burden on the institutions. Moreover, the system's ability to manage high volumes of reservations without performance degradation demonstrated its robustness and scalability.

In the area of control, the creation of individual user profiles was enabled. This feature allowed users to freely browse their reservations and monitor payment statuses, providing a personalized and transparent experience. The user profile functionality also supported enhanced data management and security, as it enabled the system to track user interactions and preferences accurately. Users could update their profiles, view their reservation history, and check the status of their payments, which improved their overall experience and satisfaction. Additionally, the system's implementation of access controls ensured that user data was protected, adhering to best practices in data privacy and security.

The presented solution was positively evaluated by users. The feedback highlighted the system's effectiveness in meeting the needs of cultural institutions and their audiences. Users praised the system for its user-friendly design, reliability, and comprehensive features. The successful integration of communication, reservation, and control functionalities into a single cohesive system demonstrated the effectiveness of the architectural decisions made during development.

References

1. Bampakos, A., Deeleman, P. (2023). *Poznaj Angular.* Gliwice: Helion.
2. Brown, S. (2017). *Visualise, Document and Explore Your Software Architecture.* Realm Academy.
3. Developers (2023). Retrieved from: https://developers.facebook.com/docs/development/create-an-app/, 10.10.2023.
4. Facebook Login (2023). Retrieved from: https://developers.facebook.com/docs/facebook-login/, 10.10.2023.
5. Gąbka, M., Kiełczyński, K., Kruszyna, R., Puchała, P. (2023). *Aplikacja mobilna i webowa do wspomagania zarządzania domami kultury.* Wrocław: Politechnika Wrocławska.
6. Gough, J., Bryant, D., Auburn, M. (2020). *Architektura API. Projektowanie, używanie i rozwijanie systemów opartych na API.* Gliwice: Helion.
7. Jemerov, D., Isakova, S. (2018). *Kotlin w akcji.* Gliwice: Helion.
8. Kotlin (2023). Retrieved from: https://www.w3schools.com/kotlin, 20.10.2023.
9. Lembo, D., Santanelli, V., Savo, D.F., De Giacomo, G., (2022). GraphOL: A Graphical Language for Ontology Modelling Equivalent to OWL 2. *Informatics Conference on Modern Trends in Multiagent Systems.* Italy, doi:10.3390/fi14030078.
10. Lis, M. (2005). *PHP i MySQL dla każdego.* Gliwice: Helion.
11. Mazur, H. (2020). *Metodyka strukturalna projektowania relacyjnych baz danych.* Wrocław: Wydawnictwo Politechniki Wrocławskiej.
12. Meta (2023). Retrieved from: https://transparency.fb.com/pl-pl/research tools/meta-content-library/, 10.10.2023.
13. Sokół, T. (2023). Retrieved from: https://tomasokol.pl/wizualizacja-architektury-zgodnie-z-modelem-c4-podejscie-praktyczne/, 20.10.2023.
14. Stasiewicz, A. (2013). *Android. Podstawy tworzenia aplikacji.* Gliwice: Helion.
15. TypeScript (2022). Retrieved from: https://2022.stateofis.com/en-US/usage/, 10.10.2023.
16. Vanderkam, D. (2020). *TypeScript: Skuteczne programowanie.* Warszawa: Promise.
17. Walls, C. (2015). *Spring Boot in Action.* Gliwice: Helion.

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STATEGIC PROJECT MANAGEMENT IN VIEW OF THE PROJECT PORTFOLIO, BENEFITS AND RESTRICTIONS

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Purpose: The article analysed and recommended the projects portfolio structure and emphasized the meaning of projects connections among each other and with the organisation's strategy. The benefits resulting from the strategic approach to the project management and its limitations were discussed. The results of our own research related to the project portfolio, the benefits from strategic project management and applied methods/methodologies within the ventures management were presented.
Design/methodology/approach: An analytical method was taken into account in the literature review. In the own reseach, statistical methods were used to analyse the data, the tool for the analysis and graphical presentation of the results was the licensed application Ms Excel version 16.81.
Findings: As a result of the analysis, an economically justified selection of projects for the portfolio is recommended. It's proposed to divide projects into: independent, dependent, complement, substitute, adaptation, mutually exclusive projects, diversification.
Originality/value: Proposing a portfolio structure, identifying the benefits and limitations of strategic project management and the results of an own research are the value of this article. It's addressed to those interested in implementing strategic project management.
Keywords: strategic project management, project portfolio, benefits, limitations.

1. Introduction

Within the space of a few decades the project management evaluated from the management of single ventures (Griffin, 2000; Lock 2009; A Guide to the Project Management…, 2013) towards the autonomic sub-discipline within social sciences, which has its own terminology as well as theoretic and methodological bases (Trocki, 2011).

In initial phases of its development the project management was operational and was focussed exclusively on the issues related to effective accomplishment of single undertakings. The project managers endeavoured to achieve the project aims at the required quality level, at a strictly defined time and without exceeding of the budget. The other aspects connected with the project's effects on the organisation or the influence on other ventures were not analysed or considered in the management.

The increased number of projects revealed some weaknesses in the operational approach to the project management. These were among other: the lack of the projects connection with the organisation's strategy, the lack of the business legitimacy of implemented projects or the endeavour to optimise the activities within single ventures which give rise to "operational islands" around the particular projects.

A complication of the management problems and increasing changeability of the organisation's environment induce the need for a simultaneous implementation of many ventures (Sheffield, Sankaran, Haslett, 2021). This makes it necessary to look at the projects management not through the outlook of single projects but through their sets, i.e. the programs and project portfolios and the whole organisation and its strategy (Trocki, Sońta-Drączkowska, 2009; Moore, 2010; Roberts, 2012).

The project portfolio is a set of the projects which are realised, financed and managed simultaneously within the same organisation or its part. The portfolio's components are the programs and single projects (Kozarkiewicz, 2014). The programs are groups of projects related by the cause and effect relationships accomplished in a coordinated way for the common superior purpose which could not be achieved by the particular projects separately. Instead, the portfolio components may but do not have to be connected and dependent on each other. All projects in the portfolio compete for the same limited resources. Therefore, the Portfolio Project Management (PPM) is aimed at optimisation of the use of the organisation's resources and the choice of the portfolio elements consistent with its strategy (Trocki, 2012; Rogowski, 2013; Cabała, 2018a).

While managing many projects in the portfolio, one draws on the single projects management output but additionally considered are specific conditions of the multi-project environment (Sońta-Drączkowska, 2012). Encroached then is the strategic management area, while an effective connection of the projects with the organisation's strategy is aimed (Kaczorowska, Słoniec, Motyka, 2019; Kaczorowska, Słoniec, Motyka, 2017; Lientz, Rea, 2002).

The exclusively operational type of the project management is no longer sufficient. Apart from the issues of effective accomplishment of single ventures it should include the common planning and allocation of resources for many projects, the development and exchange of knowledge among particular ventures, assurance of the conditions for the development of new ideas, as well as the interconnection of the projects and their relation with the organisation's strategy (Moore, 2010; Roberts, 2012; Trocki, Sońta-Drączkowska, 2009; Lientz, Rea, 2002).

2. Analysis of the composition and structure of the projects portfolio

The concentration on the direct influence of the projects on the achieved financial results causes a change of the projects management optics. More and more frequently the prospects including all projects in the organization's portfolio replace a narrow look on single, autonomic projects.

The projects portfolio is often determined for implementation of the organisation's strategic plans and confirmed in result of the occurrence of at least one of the strategic factors, such as: the market demand, strategic chance, or business requirement, the recipient's order or legal regulations.

The projects portfolio comprises all active, temporarily suspended projects, as well as those which await accomplishment, in relation to which an investment decision has already been made. The portfolio's components may be both the strategic programmes and projects, and also other – situational or spontaneous projects.

A change in the optics of the project management showed the necessity to analyse the projects including their mutual relations and coherence with the organisation's main strategy (Rogowski, 2013; Levine, 2005; Collyer, Warren, 2009).

In view of the types of interrelations between the projects in the portfolio, it is recommended to single out the categories of the projects included in Table 1.

The projects in the portfolio may be economically interrelated or not, and their mutual dependence is specified by the fact that they share the same limited resources and are to accomplish the organisation's strategic aims.

The economic relationships between the portfolio projects are very important because they show how the benefits of one project affect the benefits generated by another project or the benefits obtained from the existing and continued non-project activities of the organisation.

A special case of the economic dependence is the economic complementarity. Three cases are distinguished for it. The first case assumes that the projects enter the portfolio simultaneously and they should be accomplished almost simultaneously. In the second case the projects enter the portfolio together and accomplishment of one project enables a decrease in the costs of the other project without increasing of its costs. In the third case the projects enter the portfolio together but implementation of one project requires launching of further adjustable (enforced – defined as a must) projects which do not yield any incomes directly, moreover they induce investment outlays and costs of maintenance, which may decrease the viability of the main project. Furthermore, the adaptable projects directly affect and determine the portfolio's composition but do not maximise the organisation's value. Instead, they restrict the possibility to carry out the projects which assure the commercial benefits, involving the organisation's resources. Therefore, the portfolio's composition may not be optimal according to the value maximisation criterion.

Table 1.
Types of the projects and connections between the projects in the portfolio

Type of the project – connections between the projects	Profile
Independent project	Project A is economically independent from project B if the cash flows (CF) obtained from its accomplishment were the same, no matter if project B was carried out or not. These projects may be accomplished together with other projects of the portfolio, competing with them for mutual resources; but these are autonomous projects so their expenditures, costs and benefits are not changed in case of accomplishment or discontinuation of other projects in the portfolio
Dependent project	Project A is economically dependent on project B if CF connected with it is (or is not) determined by accomplishment of project B
Complement project	Project B is called a complement project if its implementation causes an increase of the expected advantages from project A
Substitute project	Project B is a substitute project if its accomplishment contributes to a decrease in the expected profits from project A
Adaptation project	The project whose direct purpose and cause of accomplishment is the adaptation of the company's activity to changing legal regulations and mandatory standards e.g. within the environmental protection
Mutually exclusive projects	They are used for the same purpose as specified in the strategy, therefore they are mutually exclusive; we deal with them when only one of the considered projects may be included in the portfolio
Diversification project	This project is undertaken for the diversification conducted by the business activity organisation, including the diversification of the risk connected with concentration of the activity in a specified branch, country, market or its segment

Source: Own work based on (Rogowski, 2013).

Distinguishing of substitutive projects in the portfolio requires the awareness that accomplishment of one of the projects reduces the benefit from the other projects connected by this type of the dependence.

Analysis of the structure of the organisation's projects portfolio inclines to pay attention to diversification projects. We can single out three causes of choosing diversification as the investment strategy. The first is the limiting of the entire risk of the organisation's activity resulting from its diversification. This type of diversification is used by highly specialised organisations during a crisis or worse economic situation. The second cause of using diversification is the intention to get the effect of synergy by joining of several types of the conducted activities and using mutual resources for this purpose. The third argument to apply diversification is the necessity to „rejuvenate" the organisation's business nature. For example the organisation using outdated and obsolete technologies may start using new ICT (Information and Communication Technologies).

Another important aspect connected with the projects portfolio structure is the statistical correlation (dependence) which may occur between the profits from different projects. This correlation occurs in two contexts: market and time.

deal with the market context when the benefits from two or more projects depend on the same external market conditions or on the occurrence of the same circumstances. This may be exemplified by the connection of benefits from two projects with the same target market (Zarzecki, 2008).

The time context includes a distribution in time of net profits (net cash flows) of several projects. A strong negative correlation occurs when the projects are in different phases of life. Some projects in the portfolio already generate the positive pecuniary surpluses (FCF"+") assuring the organisation's financial stabilisation, while another part is in the implementation phase so it generates negative net cash flows (FCF"-"). However, such situation does not cause any direct risk for the company's financial stability. On the other hand a strong positive correlation between the net cash flows generated by the projects situated in the portfolio occurs when in the same period most of the portfolio projects are in the same implementation phase. This is because these projects generate only negative net cash flows, which in a longer outlook may be a significant hazard for the company's solvency.

The organisation's strategic plans should determine the portfolios' components hierarchy. Consequently, excluded from the portfolio may be those components which contribute in the least degree to implementation of the objectives noted in the organisation's strategy. In this way the organisation's strategy becomes the main factor according to which the projects are invested. Simultaneously, the portfolio's components, through the reports about the stage of performance and demanded changes become a source of returnable information for other programs and projects. On the other hand, the requirements of other particular components connected with the resources are communicated on the portfolios level, which favourably affects the organisational planning.

The value of the projects portfolio depends on the type of activity conducted by the organisation, and consequently defined in the strategy of the goals which are to be achieved due to implementation of the projects within the portfolio.

For the best possible use of the limited resources from the organisation's (or its part's) point of view, the projects' portfolio is subjected to the processes defined as the projects portfolio management (PPM) (Cabała, Paluch, 2020; Cabała, 2018b; Kozarkiewicz, 2012).

The current project portfolio management takes place both on the strategic and operational level. An example of the strategic decisions related to the whole portfolio may be the systematic adjustment of the portfolio's composition and structure aimed at achievement of the demanded results. Instead, the projects scheduling in the portfolio or taking the decisions related to particular projects in the portfolio are operational procedures.

One of the sub-processes of the projects portfolio management process (Trocki, 2012; Kaczorowska, Słoniec, Motyka, 2017) is categorisation during which the portfolio's components are arranged through attribution to specific categories due to similar purposes and predefined evaluation criteria (Cabała, Paluch, 2020; A Guide to the Project Management…, 2013). The article recommends the division in view of the type of the connection between the projects, acknowledging that it enables the economically justified selection of the projects to the portfolio.

3. Benefits and restrictions of the strategic approach to the project management

The strategic management of the projects uses and combines the output from the projects management areas (among other the detailed methods and tools, management of knowledge in the projects) as well as the strategic management (including the tools of the analysis of organisation and its environment, portfolio methods, principles of formulation and implementation of strategies). This approach responds to the current needs of the management practice and yields many measurable benefits. However, it seems to be more developed in theory than in practice. Therefore, the unquestioned benefits resulting from the use of the strategic management of projects are also accompanied by many doubts and restrictions. The benefits and restrictions are presented in Table 2.

Table 2.
Benefits and restrictions connected with implementation of the strategic management of the projects

BENEFITS	RESTRICTIONS
Coherence of the projects aims with the aims included in the organization's strategy	Excessive restriction of the organisation's flexibility in case of having a very detailed and formalised project management strategy
Having the project's portfolio adapted to the organisation's situation and purposes	The time horizon of the projects management strategy is not adjusted to the project's category, environmental dynamics and the period assumed in the superior strategy (organisation's strategy)
Forming the transparent and clearly communicated relations between the projects in the portfolio	A person or individual responsible for the preparation and implementation of the project management strategy
A possibility to use mutual methods, standards and tools of the project management	Unfavourable attitudes of the executive personnel, i.e. the supreme management and project managers
Assuring a uniform IT support in the whole organisation	
Facilitated exchange of the knowledge and experience	
Promotion of the choice and education of employees for projects accomplishment requirements	
Development of the project management strategy and its position in relation to the superior strategy of the organisation and other functional strategies	
Existence of the project management office	

Source: Own work based on (Lichtarski, 2013; Lichtarski, Wąsowicz, 2014; Kerzner, 2005).

The strategic project management assumes the interrelation of realised projects with the organisation's strategy and among each other. This creates two types of benefits. First, the organisation implements the projects which contribute to achievement of the organisation's strategic goals, justified in view of the conducted activity, which is favourable for the organisation. Secondly, the projects enrolled in the organisation's strategy are understood better and receive more support, which is advantageous for the project. The organisation's managerial staff should coordinate the construction of the projects portfolio

and establish the priorities of particular undertakings. The aspect of projects interrelationship – sharing the resources - appears here. On the one hand, the more resources are shared among the projects, the higher the need to coordinate the activities and exchange information. On the other hand, the interdependence of resources leads to the intra-organisational fight, especially if there is too little of a given resource or it is encumbered (Lichtarski, Wąsowicz, 2014).

Having a portfolio adjusted to the organisation's situation and purposes results in searching for optimisation in the scale of the whole organisation and not only single projects. The portfolio includes then the profitable ventures. Besides, a selection of the projects for the portfolio in view of the cycle of their life is crucial, as is - consequently - the demand for the resources and generated incomes (portfolio methods).

The development – among the project teams – of complex but clearly communicated relations based on cooperation, non-destructive competition or co-option creates the values for the whole organisation. For example, due to the construction of relations using co-option, in certain areas the teams cooperate (training courses, implementation, use and development of mutual methods, standards and project management tools, which facilitates the communication and increases the efficacy of applied instruments), while in other areas they compete (e.g. gaining of resources, prestige).

Acquisition of uniform IT support not only reduces the total costs of information technology but also accelerates the process of the project portfolio management implementation. Many information systems supporting the project portfolio management are available on the market.

Uniform methods, standards and information support facilitate the exchange of knowledge and experience among the project teams and increase the functionality of applied standardised tools.

The PPM supports the selection of employees for projects accomplishment and improvement of essential competences, combined with the personal strategy.

One of the institutional symptoms of the strategic functioning of the project management in organisation is the project management office. Usually its appointment is caused by the requirement to coordinate the project management tasks. The vast spectrum of its activities comprises especially: development of the project management methods, creation of a set of the best practices, management of the documentation of the acquired experience, and conducting of training courses (Kerzner, 2005). The project management office existing on the highest level in the organisation allows to concentrate on strategic tasks instead of the activities of particular organisational divisions. This supports a better control of using the resources, coherence of the conducted projects with the organisation's strategy and strategic aims, undertaking the activities aimed at the selection of ventures in view of their profitability and mutual conformity, and implementation of uniform methods and tools.

The projects management strategy may be included in relation to other strategies in two ways. In the first one the project management strategy occurs as a separate functional strategy equivalent to other functional strategies. Such location of the project management strategy assures its relative independence, which may result in a higher level of the projects autonomy. An inconvenience of such a way of inclusion is the difficulty in coordination with other functional strategies at the stage of planning and accomplishment. The other way of including the strategy locates it as a cross-sectional strategy in relation to functional strategies. An advantage of such location is the occurrence of common areas, which on the one hand contributes to coherence and mutual support, but on the other hand it may cause conflicts at determination of the subjects responsible for implementation of the project management strategy.

The doubts connected with minuteness and formalisation of the projects management strategy are justified considering the domination of the planning school at its formulation. However, the strategy not necessarily confines the organisation's flexibility because it does not have to be in the form of a detailed plan or be based on the planning school assumptions.

In the companies which work in a variable environment where the products life cycles are short while the projects are implemented at a short time, e.g. in ICT sector, the time horizon will be shorter than in sectors of a higher stability and longer projects accomplishment time, e.g. in the building trade.

Furthermore, there are restrictions as to who is to be responsible for the design and implementation of the project management strategy: should it be the chief management, the projects managers team, or another internal entity, such as e.g. the design office. Most justified seems to be entrusting the tasks connected with preparation and implementation of the project management strategy to such entity but the research indicates that over a half of the building contractors do not have such a facility (Wyrozębski, Juchniewicz, Metelski, 2012).

Looking at the project management strategy from the planning point of view (a long time horizon, high degree of formalisation, lack of flexibility) causes scepticism and resistance of the chief management and project managers against the strategic approach to the projects. Resistance of the chief managers has its source in a failure to perceive the need to look at the organisation's project management comprehensively, and may also result from the necessity to take inconvenient decisions or firm activities, such as e.g. imposing shared methods, standards and tools on the project teams. The project managers may be less (as compared to the chief managers) adversely or sceptically disposed to the activities connected with implementation of the strategic approach to the project management in organisation. This may result from the managers' fear of the confinement of their autonomy in project implementation, central allocation of resources or uniform project management instrument imposed from above.

4. Research section

4.1. Research purpose, research methodology, research sample characteristics

The analyses presented in this section were based on quantitative surveys of enterprises and organisations.

The purpose was to explore strategic project management in organisations from the perspective of the project portfolio and its benefits.

The following research questions were posed to achieve the research objective:

1. Which project categories are distinguished in the project portfolio depending on the company's size and reach?
2. Which benefits of strategic management do respondents perceive depending on the company's size and reach?
3. If the company does not have a project portfolio, is the benefit of strategic project management perceived?
4. Do the distinguished project portfolio categories depend on the strategic management benefits?

Additionally, the frequency of use of particular project management methods/ methodologies was investigated by posing the research question:

5. Which project management methods/methodologies are most commonly used and whether their use depends on the company's size and scope?

The survey was conducted using the CAWI (Computer Added Web Interview) method and involved 300 enterprises. The research was conducted in the first quarter of 2023 in Poland, by an external organisation. Statistical methods were used to analyse the data, the instrument for the analysis and graphical presentation of the results was the licensed application MS Excel version 16.81.

The characteristics of the enterprises surveyed are presented in Table 3.

Table 3.
Survey sample characteristics for n = 300

Characteristic feature		percentage
Year of enterprise establishment in years	before 1980	10.0
	1981-1990	14.3
	1991-2000	30.7
	2001-2010	28.3
	2011-2020	15.3
	after 2020	1.4
Enterprise size	Micro	12.3
	Small	42.3
	Medium	29.3
	Large	16.1
Dominant scope of the market activity	Local	12.3
	Regional	21.0
	National	40.0
	International	26.7

Source: Own work.

Characterising the research sample, it should be noted that more than half of the enterprises surveyed (55%) were founded in the 20th century and 45% in the 21st century. 15% of the enterprises are young, established within the last 10 years. In the surveyed group, small enterprises (10-49 employees) account for the largest number (42.3%), medium-sized enterprises (50-249 employees) for 29.3%, large enterprises (more than 249 employees) for 16.1% and micro enterprises (0-9 employees) for 12.3%. Among the surveyed companies, the national market activity (in terms of turnover) is dominant (40%), 26.3% of the surveyed enterprises operate on the international market, 21% on the regional market (voivodship area) and 12.3% on the local market (district area).

4.2. Research results

The results of the answers to the first research question 1 about the project categories in the project portfolio according to the enterprise size and the enterprises' activity scope are presented in Tables 4 and 5.

Table 4.
Category structure of the project portfolio in large, medium, small or micro-enterprises, percentage

Enterprise size	Lack of a project portfolio	Investment projects	ICT projects	Research and development projects
Micro (0-9 employees)	69.7	75.7	0.0	77.0
Small (10-49 employees)	21.3	0.0	78.0	0.0
Medium (50-249 employees)	6.3	0.0	0.0	0.0
Large (over 249 employees)	2.7	24.3	22.0	23.0

Source: Own work.

Micro-enterprises overwhelmingly (almost 70% of indications) lack a project portfolio. This is understandable, as micro enterprises have few projects (limited needs and financial resources). Investment projects are most frequently conducted by small enterprises (75.7%), while research and development projects are conducted by micro-enterprises (77%). The reason for such a high percentage of R&D projects in micro enterprises may be explained by the fact that they were set up to develop or implement the founders' ideas. National and international funding for implementation projects can also be an incentive.

Table 5.
Category structure of the project portfolio in enterprises with local, regional, national and international scope, percentage

Scope of the enterprises' activities	Lack of a project portfolio	Investment projects	ICT projects	Research and development projects
Local	66.7	75.7	0.0	77.0
Regional	10.0	0.0	78.0	0.0
National	17.7	0.0	0.0	0.0
International	5.6	24.3	22.0	23.0

Source: Own work.

Investment projects are most often (75.7%) realised by enterprises with a local scope, less often by enterprises with an international scope (24.3%). However, ICT projects with a regional scope account for 78%, R&D projects for enterprises with a local scope 77%, and less frequently (23%) with an international scope. The results of the responses to the second research question are presented in Figures 1 and 2.

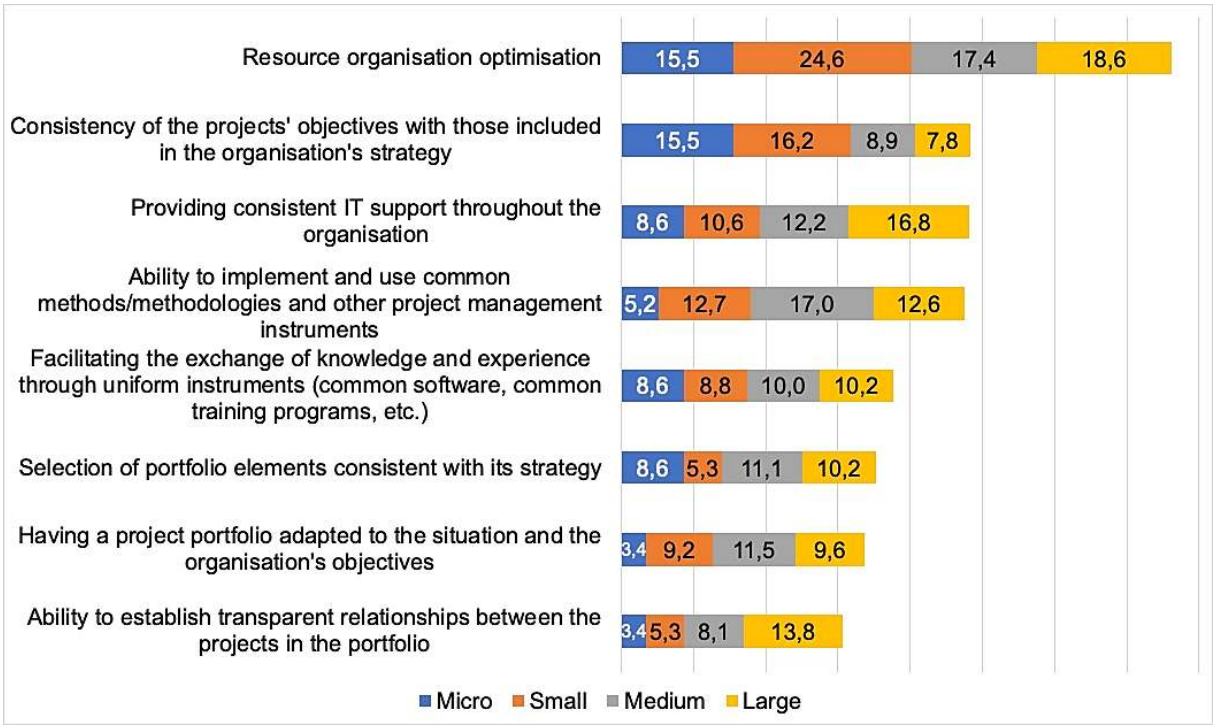

Figure 1. The benefits of strategic project management depending on the organisation's size, percentage. Note. only respondents' answers indicating benefits were included

Source: Own work.

Analysing the data in Figure 1, it should be noted that in all enterprises, organisational resource optimisation was identified as the primary benefit of strategic project management (more than 50% of indications). Other important benefits of strategic project management include the ability to implement and use common methods/methodologies and other project management instruments (over 35% of indications) and providing consistent IT support across the organisation (over 30% of indications).

In large enterprises, the most important benefits of strategic project management are the organisational resource optimisation (10.3%) and the provision of consistent IT support across the organisation (9.3%), while in medium-sized enterprises, the most important benefits are the organisational resource optimisation (15.7%) and the ability to implement and use common methods/methodologies and other project management instruments (15.3%). In small organisations, organisational resource optimisation was indicated most frequently as a benefit (23.3%). Other benefits perceived in micro-enterprises included: facilitating cooperation with partners abroad, facilitating the search for partners and reducing costs.

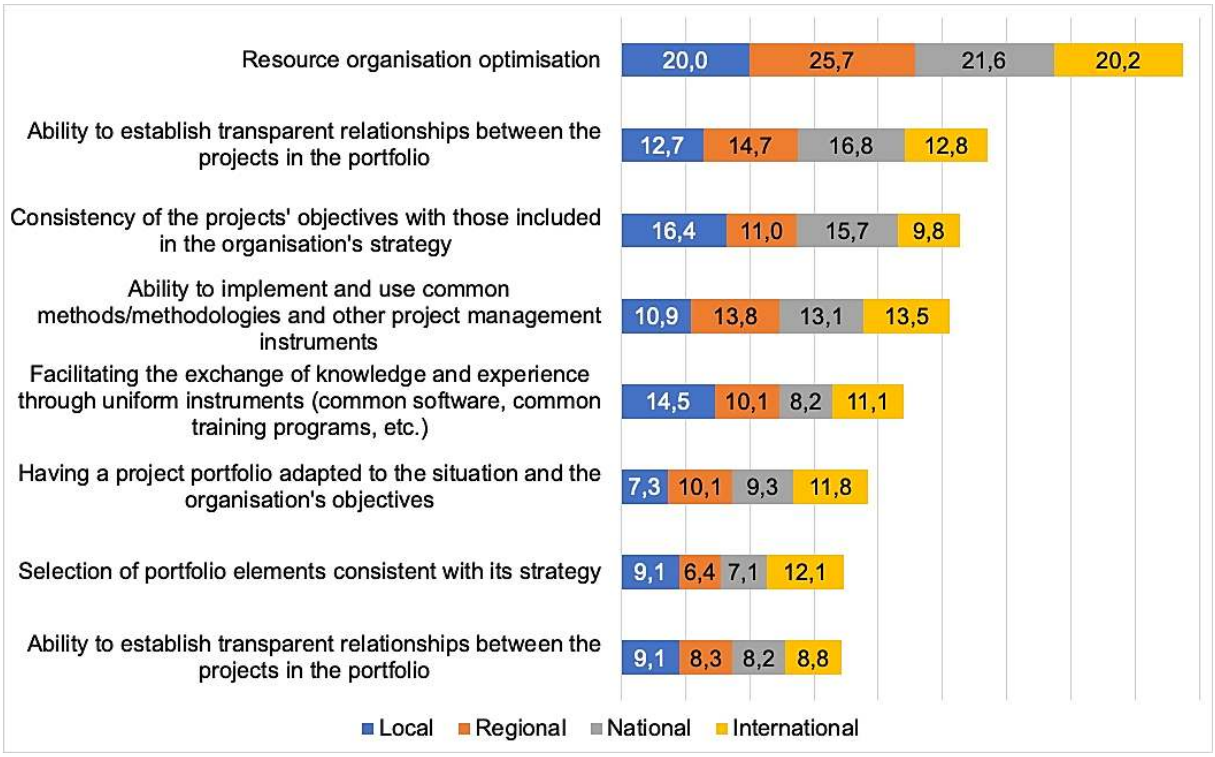

Figure 2. Benefits were included.

Source: Own work.

Assessing the benefits of strategic project management according to the organisation's scope of activity, it should be noted that the most frequently indicated benefit was organisational resource optimisation (almost 90% of respondents). Enterprises with an international, national, regional and local scope indicated especially this benefit most frequently.

To address the third research question, Pearson correlation coefficients were determined between the benefits of strategic project management and the individual project portfolio categories. The determined coefficients are presented in Table 6.

Table 6.

Pearson correlation coefficients

Benefits of strategic project management / Project portfolio categories	Consistency of project objectives with those included in the organisation's strategy	Selection of portfolio elements consistent with its strategy	Optimisation of the organisation's resources	Having a project portfolio adapted to the situation and the organisation's objectives	Possibility of forming transparent relationships between projects in the portfolio	Ability to implement and use common methods/ methodologies and other project management instruments	Providing consistent IT support across the organisation	Facilitating the exchange of knowledge and experience through the use of uniform instruments (uniform software, common training programmes and others)
Lack of a project portfolio	-0.041	-0.340	-0.270	-0.377	-0.299	-0.305	-0.239	-0.309
No category	0.072	0.207	0.230	0.202	0.215	0.216	0.089	0.152
Investment projects	0.128	0.274	0.012	0.283	0.075	0.215	0.144	0.360

Cont. table 6.

ICT projects	0.048	0.179	0.056	0.214	0.166	0.096	0.015	0.219
Research and development projects	0.066	0.201	0.093	0.252	0.249	0.325	0.236	0.312

Note: Negative Pearson correlation coefficient means a negative relationship between the variables, that is, when one variable takes high values the other takes low values.

Source: Own work.

The highest Pearson correlation coefficients reach a value of around 0.3, meaning they are average. No relationship was found between the project portfolio categories and the benefits of strategic project management.

It should be concluded that if an organisation does not have a project portfolio they do not see the benefits of strategic project management (average correlation).

Additionally, the project management methods/methodologies used were examined by analysing the answers to the fifth research question. The results of this analysis are presented in Figure 3.

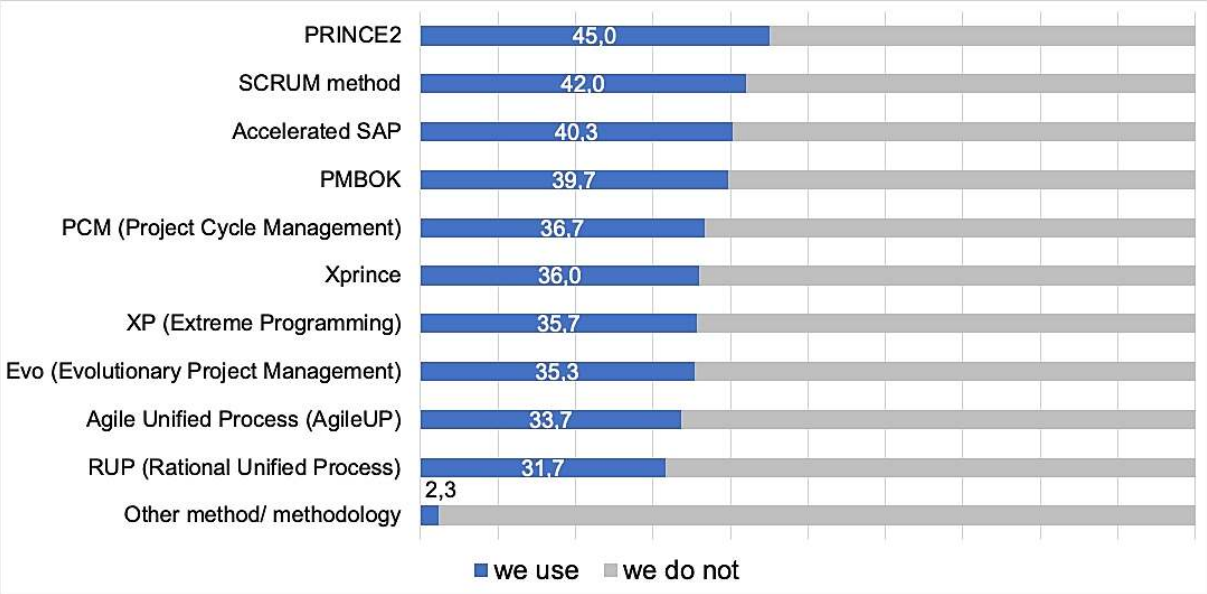

Figure 3. Most frequently used project management methods/methodologies, percentage.

Source: Own work.

The most commonly used project management methodology is Prince2, used by 45% of the enterprises surveyed. This is followed by the SCRUM method, used by 42% of enterprises, and Accelerated SAP used by 40.3% of organisations. The oldest, traditional project management methodology PMBOK is used by 39.7% of enterprises. The percentage of other project management methods used is higher than 30%. The least frequently used methods/ methodologies are: Rational Unified Process (31.7%), Agile Unified Process (33.7%) and Evolutionary Project Management (35.3%). Only 7 out of 300 enterprises used other project management methods. These include the ITDT method, Extend disk 1, SWIS methodology, Waterfall, Evo project time and other proprietary methodologies.

Further response analysis results to the fifth research question are presented in Tables 7 and 8.

Table 7.
Structure of the individual project management methods/methodologies used in large, medium, small or micro-enterprises, percentage

Enterprise size	PMBOK	PRINCE2	PCM (Project Cycle Management)	RUP (Rational Unified Process)	Accelerated SAP	SCRUM method	XP (Extreme Programming)	Xprince	Evo (Evolutionary Project Management)	Agile Unified Process (AgileUP)	Other method/ methodology
Micro	7.7	10.3	10.3	10.3	9.0	10.3	10.3	9.0	10.3	10.3	2.6
Small	11.7	13.2	9.2	8.5	8.7	11.7	9.5	10.4	9.2	7.5	0.5
Medium	10.4	11.1	10.2	8.4	12.1	11.4	8.8	8.6	9.5	9.3	0.2
Large	9.4	11.6	9.4	7.6	12.1	9.8	10.3	9.8	8.9	10.3	0.9

Source: Own work.

In micro-enterprises, different types of methods and methodologies are used to a similar extent. In small businesses, PRINCE2, PMBOK and SCRUM methods are most commonly used. Accelerated SAP, SCRUM and PRINCE2 are most frequently used in medium-sized enterprises. In large businesses, traditional Accelerated SAP and PRINCE2 methodologies are among the most commonly used.

Table 8.
Structure of individual project management methods/methodologies used in local, regional, national and international companies, percentage

Scope of the enterprises' activities	PMBOK	PRINCE2	PCM (Project Cycle Management)	RUP (Rational Unified Process)	Accelerated SAP	SCRUM method	XP (Extreme Programming)	Xprince	Evo (Evolutionary Project Management)	Agile Unified Process (AgileUP)	Other method/ methodology
Local	9.0	10.1	10.1	10.1	9.6	10.6	10.1	9.6	10.1	9.6	1.1
Regional	10.3	10.7	9.7	9.3	9.7	10.3	9.7	10.0	10.0	10.0	0.3
National	11.3	13.2	10.5	7.5	10.2	11.6	8.9	9.2	9.2	7.5	0.8
International	10.5	12.7	8.3	7.2	13.0	11.6	9.4	9.4	8.3	9.1	0.4

Source: Own wok.

Analysing the data in Table 8, it can be concluded that no project management methods/methodologies are used far more frequently by companies with a local, regional, national or international scope.

5. Conclusion

The strategic project management complies with the comprehensive look on the project implementation, assuring the projects relation with the organisation's strategy. The coherence of the projects goals with the organisation's goals guarantees realization of the projects which contribute to achievement of the organisation's strategic objectives according to its basic activity.

The advantages of the strategic project management include among other: the care of the projects coherence with the organisation's strategy and strategic goals, selection of enterprises in view of their profitability and mutual conformity, the projects portfolio management, the care of implementation of uniform methods, tools and IT systems, and providing organisational, material, personnel and information conditions for the development of new ventures.

Nevertheless the measurable profits resulting from implementation of this approach are accompanied by some restrictions. Perceiving the projects management strategy only in the planning depiction may impede implementation of the strategic project management and after its implementation it may contribute to the decrease in the organisation's flexibility.

However, the measurable profits resulting from implementation of this approach are accompanied by some restrictions. Perceiving the project management strategy only in the planning depiction may hinder implementation of the strategic projects management; after its implementation it may cause the organisation's decreased flexibility.

The strategic project management is an approach which allows, at least partly, to eliminate or counteract the indicated limitations of the operative venture management. It is an integrated and complete approach to projects administration because it is an integrated, comprehensive approach to implementation of projects in a given unit, which is aimed at an achievement of the best effects in the scale of the entire organisation.

We should assume that this approach will have a better chance of success in those organisations where the projects are common and the managers perceive the need to join the project management and strategic management spheres. More favourable conditions for implementation will apply to the strategic project management also in those organisations where the demand for a complex approach to management of many ventures realised simultaneously is noticed. The strategic project management seems to be particularly useful in those entities which realise many projects and ventures which are very important for the organisation's development and survival. Taken into account should be also the companies whose income generated by the projects in relation to Besides, taken into account should be the revenue generated by the projects in relation to the income generated from other activities is considerable.

The development of the strategic management of projects in organisation is conditioned by many factors – internal and external alike. These include: convergence (similarity) of the objectives of projects and organisation, type of the organisational structure, existence of the project management office, level of the staff's competences within the project management, style of management, type of organisational culture, support of the general management, competitiveness of superior management and environmental competitiveness. The mentioned factors, depending on the intensity, may stimulate or confine the development of the strategic management of projects (Lichtarski, Wąsowicz, 2014).

Own research concerned strategic project management in organisations from the perspective of a project portfolio and the benefits of having one. This quantitative survey was conducted using the CAWI (Computer Added Web Interview) method in the first quarter of 2023 in Poland. The research sample included 300 organisations. After analysing the data, the research questions were addressed. Micro-enterprises overwhelmingly do not have project portfolios, which is understandable given their limited needs and financial resources. Small, and locally based enterprises most often conduct investment projects, while locally based micro-enterprises conduct research and development projects. Micro-enterprises are often created precisely to develop and implement their founders' intentions and are further encouraged to implement ventures through national and foreign funding for implementation projects. The primary benefit of strategic project management is the organisational resource optimisation across all businesses regardless of category. No correlation was seen between project portfolio categories and the benefits of strategic project management. The most commonly used project management methods/methodologies are: Prince2, SCRUM and Accelerated SAP. None of the methods/methodologies are particularly readily used by organisations of different sizes and with different scopes of activity.

The strategic management of projects is an approach in a continuous stage of development and is not often used in practice. Properly implemented and used it may become a remedy for the problems connected with simultaneous realisation of many projects.

References

1. *A Guide to the Project Management Body of Knowledge* (2013). USA: Project Management Institute.
2. Cabała, P. (2018a). Proces budowy strategii portfela projektów. *Studia i Prace Kolegium Zarządzania i Finansów, No. 159*, pp. 93-106.
3. Cabała, P. (2018b). *Zarządzanie portfelem projektów w organizacji: koncepcje i kierunki badań.* Kraków: Mfiles.pl.

4. Cabała, P., Paluch, W. (2020). Modele zarządzania portfelem projektów. *Przegląd Organizacji*, *No. 12*, pp. 19-26, doi: 10.33141/po.2020.12.03.
5. Collyer, S., Warren, C. (2009). Project Management Approaches for dynamics environments. *International Journal of Project Management*, *Vol. 27*, pp. 55-364.
6. Griffin, R.W. (2000). *Podstawy zarządzania organizacjami*. Warszawa: PWN.
7. Kaczorowska, A., Słoniec, J., Motyka, S. (2017). Strategiczne zarządzanie projektami. *Ekonomika i Organizacja Przedsiębiorstwa*, *No. 12*, pp. 21-31.
8. Kaczorowska, A., Słoniec, J., Motyka, S. (2019). Portfolio approach to project management in creation of the organization's value. *MATEC Web Conf., Vol. 252*. Retrieved from: https://doi.org/10.1051/matecconf/201925206011.
9. Kerzner, H., (2005). *Advanced Project Management*. Warszawa: One Press.
10. Kozarkiewicz, A. (2012). *Zarządzanie portfelami projektów*. Warszawa: PWN.
11. Kozarkiewicz, A. (2014). Portfel projektów jako sieć organizacji tymczasowych. In: A. Sopińska, S. Gregorczyk (Eds.), *Granice strukturalnej złożoności organizacji*. Warszawa: Oficyna Wydawnicza Szkoły Głównej Handlowej.
12. Levine, H.A. (2005). *Project Portfolio Management: A Practical Guide to Selecting Projects, Managing Portfolios, and Maximizing Benefits*. John Willey & Sons.
13. Lichtarski, J.M. (2013). Strategiczne zarządzanie projektami. *Prace naukowe Uniwersytetu Ekonomicznego we Wrocławiu, No. 277*, pp. 40-51.
14. Lichtarski, J.M., Wąsowicz, M. (2014). Uwarunkowania rozwoju strategicznego zarządzania projektami w organizacji. *Organizacja i Kierowanie*, *No. 1A*, pp. 123-134.
15. Lientz, B.P., Rea, K.P. (2002). *Project Management for the 21st Century.* London: Academic Press.
16. Lock, D. (2009). *Podstawy zarządzania projektami*. Warszawa: PWE.
17. Moore, S. (2010). *Strategic project management*. *Enabling a Productive Organization*. New Jersey: Wiley & Sons.
18. Roberts, P. (2012). *Strategic project management. Creating the Conditions for Success*. London: Kogan Page.
19. Rogowski, W. (2013). *Ocena projektów – koncepcje i metody*. Warszawa: Oficyna Wydawnicza Szkoły Głównej Handlowej, pp. 43-76.
20. Sheffield, J., Sankaran, S., Haslett, T. (2012). *System Thinking: Taming Complexity in Project Management*. On The Horizon, Emerald Group Publishing Limited. Retrieved from: http:// http://hdl.handle.net/10453/22564, 12.03.2024.
21. Sońta-Drączkowska, E. (2012). *Zarządzanie wieloma projektami.* Warszawa: PWE, pp. 44-87.
22. Trocki, M. (2012). *Nowoczesne zarządzanie projektami*. Warszawa: PWE, pp. 387-395.
23. Trocki, M. (Eds.) (2011). *Metodyki zarządzania projektami.* Warszawa: Bizarre, pp. 9-10.
24. Trocki, M., Sońta-Drączkowska, E. (2009). *Strategiczne zarządzanie projektami*. Warszawa: Bizarre, pp. 15-34.

25. Wyrozębski, P., Juchniewicz, M., Metelski, W. (2012). *Wiedza, dojrzałość, ryzyko w zarządzaniu projektami. Wyniki badań*. Warszawa: Oficyna Wydawnicza SGH.
26. Zarzecki, D. (2008). *Zarządzanie finansami firm – teoria i praktyka*. Wrocław: Wydawnictwo Akademii Ekonomicznej im. Oskara Langego we Wrocławiu, p. 626.

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SHOULD WE ISOLATE INNOVATIVE PROJECTS?

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Purpose: The research aims to explore whether innovative projects should be isolated within organisations. The motivation behind this research stems from previous findings indicating a divide between popular project management methodologies and strategic innovation management literature regarding the isolation of innovative projects.
Design/methodology/approach: The primary research method is a survey-based study, in which questionnaires were distributed to project managers. The surveys collected data on innovative projects, focusing on such aspects as project isolation, project outcomes (short-term efficiency and long-term preparation), and organisational culture. Statistical methods are used to analyse the relationship between project isolation and the success metrics.
Findings: Projects that were not isolated from the rest of the organisation tended to achieve greater short-term success. These projects were more likely to meet deadlines, stay within the budget and fulfil the project scope. Regular communication and collaboration with the broader organisation helped to access resources, improve decision-making and ensure project alignment with organisational objectives. The results did not strongly support the hypothesis that isolating projects leads to the development of new norms and values that prepare the organisation for future challenges.
Research limitations/implications: The study focuses primarily on organisations with conservative, process-driven business models where innovation is not the core activity. This limits the generalisability of the findings to more innovation-focused organisations such as tech startups or R&D-heavy companies. The research relies on self-reported data from project managers, which may introduce biases.
Practical implications: The practical implications of the paper suggest that organisations should tailor their management of innovative projects by deciding when to isolate project teams to foster creativity and learning and when to integrate them with the rest of the organisation to enhance short-term efficiency.
Originality/value: The paper provides new empirical data on the relationship between project isolation and both short-term and long-term success metrics. The paper critically examines the role of project isolation considering popular project management standards. It also highlights how project isolation affects the development of new norms and values, which may be crucial for the organisation's future flexibility and competitiveness.
Keywords: innovative project, strategic innovation, project management.
Category of the paper: research paper.

1. Introduction

BCG's 2023 study on building resilience and competitive advantage involved top executives from companies around the world (BCG, 2023). These companies belonged to a variety of industries and included technology, industrial, medical and financial companies. They varied in size and geographical coverage. As a result, it was found that 79% of the companies worldwide regard innovation as one of their top three priorities and 66% plan to increase spending on innovative projects. From the projects listed in the document, it is expected that they will influence a change in the way organisations are managed. In particular, executives plan to strengthen the resilience of their organisations, increase the focus on sustainability, accelerate digital transformation and introduce new operating models that better address global challenges and uncertainties. These changes aim to increase the flexibility and adaptability of companies in the face of a rapidly changing business environment. In other words, innovative projects are to be the source of new management models.

This signalling of the importance of innovative projects by the respondents draws attention to the challenges that must be faced in their implementation. For, if the innovativeness of a project is considered to be the degree to which the way of proceeding in the project differs from what has been done so far in the organisation (cf., e.g. Griffin, 1997; Shenhar, Dvir, 2008; Kiełbus, 2011; Trocki, 2012), then in highly innovative projects (the so-called "breakthrough projects") the previous ways of doing things must be abandoned and proven practices should be replaced by action based on the trial-and-error method. Shenhar and Dvir (2008) additionally point out that creative people with the ability to innovate across disciplines and with the freedom to express and test new ideas are sought for breakthrough projects. These people should – at least partially – move away from existing patterns by developing new ways of doing things.

This different approach to the implementation of highly innovative projects affects, among others, the way in which they are positioned within the structures of an organisation. A critical analysis of the literature on the subject reveals a divergence of views regarding the isolation of innovation-related projects from organisation structures (cf., e.g. Trocki, 2009; Galbraith, 1999; Zgrzywa-Ziemak, Kamiński, 2009; Kamiński, Rosłoń, 2023). These discrepancies are particularly evident between popular project management methodologies and the literature on innovation and strategic management, which will be discussed in more detail later in the article. In order to dispel these doubts, the research team conducted their own studies in this area (Kamiński, Rosłoń, 2023). Thus, they showed some poor differences in the learning of project teams that were in isolation from the rest of the organisation compared to teams where interaction between project team members and the rest of the organisation was fostered. A cautious suggestion was then made on the basis of the findings. As a matter of fact, in organisations of a rather conservative nature, i.e., where the core business does not involve

unique projects and is process-oriented in nature, the number of interactions between the learning project team and the rest of the organisation should – to some extent – be limited. This is because the isolation of an innovative project limits the take-up of existing organisational solutions (*e.g.*, experience gained over many years) by the team and provides a basis for learning and developing new ways of working.

Unfortunately, the conclusions formulated at the time were based on very weak differences in the results obtained from the empirical studies. This dictates both a great deal of caution regarding the treatment of the conclusions themselves and prompts further research. Therefore, the article aims to answer the question whether to isolate innovative projects or not. In this case, the answer is to be obtained by using the dimensions of project success, as defined by Shenhar and Dvir (2008), in projects with varying degrees of isolation. Accordingly, the study uses both a short-term measure that focuses on the efficiency of the project and a long-term measure that assesses the project in terms of the preparation for the future that the project gives to the organisation. In the first case, therefore, an assessment will be used to determine whether the project meets the three constraints, i.e., whether it is delivered on time, within budget and according to the specification. In the second case, to answer the question whether the project is preparing the organisation for the future, the cultural metaphor of the organisation will be used (Sułkowski 2004). It was assumed that the transformation of the project team's cultural norms and values from those of the existing organisational culture could prepare the organisation to take on new challenges that require a different response.

The article consists of three main parts. In the first part, the issue of assessing project success will be addressed; it will therefore present Shenhar and Dvir's (2008) dimensions of project success. In the second part, two research hypotheses will be introduced. In the third part, the hypotheses will be verified by empirical research and discussed.

2. Assessment of project success

Focusing considerations on project success forces the definition of project success criteria. The author of an extensive discussion on this topic is Klaus-Rosińska (2019). Based on her analysis of the literature, she concludes that there is no single universal list of "success criteria" that fits all types of projects. Thus, success criteria will vary in projects depending on many aspects, including the size or complexity of the project (cf., e.g. Westerveldt, 2003). Success criteria are usually associated with the iron triangle of a project, i.e., cost, time and quality (Pinto, Slevin, 1988; Chan et al., 2002). However, many researchers stress that even taking all the cited criteria into account at once, assessing the success of a project by means of them will be insufficient (Atkinson, 1999; Judgev, Müller, 2005; de Wit, 1988). Above all, they do not take into account whether the project product has met the end-users' needs (Baker et al., 1988).

Klaus-Rosińska (2019) ultimately concludes that success can mean something different to different stakeholders. Success criteria should comprehensively reflect different interests and lead to a multidimensional approach to assessing success.

One model for assessing the success of a project that takes into account the satisfaction of the needs of different stakeholders as well as the link between these criteria and the different phases of the project life cycle is the model developed by Shenhar, Dvir, Levy and Maltz (2001). Thus, Shenhar and Dvir (2008) note in their book that assessing the success of a project on the basis of meeting three constraints – delivery on time, within budget and according to the specification – is no longer sufficient. Thus, the cited authors propose a full assessment of project success in the short and long term based on five basic groups of measures: (1) the efficiency of the project, (2) its impact on the client, (3) its impact on the team, (4) business and immediate success and, ultimately, (5) preparation for the future.

Thus, in the shortest term, the measure of project efficiency refers to whether the project was completed as planned, on time and whether expenditure was within the budget. In this case, meeting the resource constraints indicates that the project was effectively and efficiently managed. The impact of the project on the client is then assessed. This measure represents the key stakeholders whose perception is critical to the success of the project. The third measure, team impact, reflects how the project impacts the team and its members. The fourth measure – business and immediate success – reflects the direct and immediate impact the project has on the parent organisation. Ultimately, in the longest term, the project is assessed to prepare for the future. This measure reflects the extent to which the project will help the organisation prepare its infrastructure for future needs and how it will create new opportunities. Future infrastructure may include new organisational processes as well as additional technical and organisational competences; it may also improve management capabilities.

In the context of considering innovative projects, it should be noted that they are characterised by both a higher degree of risk and the fact that they offer greater opportunities for growth and success. According to Shenhar and Dvir (2008), the measure of success should reflect these opportunities, which means that rather long-term measures should be used for innovative projects. As they write, for low-risk projects, meeting resource constraints may be more critical and appropriate than for higher-risk projects. The immediate success of low-risk projects is based on meeting budget and time constraints and potential returns can be determined in advance. In contrast, for high-risk and highly uncertain projects, poor short-term performance, budget overruns and even limited business success can be offset by long-term benefits such as the creation of new markets, the development of knowledge in new technologies and the preparation of the infrastructure for more advanced products created in the future. Because of the importance, measures of project success change along with the level of risk and uncertainty.

Consequently, as no set of dimensions can serve all projects, managers must, according to Shenhar and Dvir, adapt their expectations to the type of project and the importance of different measures of success. For example, a project with high uncertainty and high risk will be assessed primarily on the basis of business and long-term facts rather than on the basis of short-term measures related to time and budget execution. In contrast, a project with a low level of uncertainty and low risk is unlikely to help the organisation develop new technologies or create new opportunities and should, therefore, be assessed on the basis of short-term metrics. These differences should become an integral part of project planning and be taken into account when making key decisions, including, as it seems, decisions to isolate highly innovative projects. Thus, the decision concerning whether to foster interaction between the project team and the rest of the organisation should be analysed in the context of two different dimensions of project success: the efficiency of the project and the preparation for the future that it offers.

3. Project management standards and methodologies and the isolation of highly innovative projects

To answer the question whether to isolate highly innovative projects, one can refer to the most popular project management standards and methodologies. And so, according to the PRINCE2 methodology, the project team should not be isolated. Indeed, the methodology places a strong emphasis on communication, collaboration and stakeholder engagement. Furthermore, in the PRINCE2 methodology, a project is a management environment created to deliver one or more business deliverables according to the specific requirements of the business. This, therefore, does not indicate a universal solution to be implemented for every project but rather a flexible structure that can be easily adapted to each type of project and its context (Office of Government Commerce, 2010). This alignment will not be possible without numerous interactions between the project team and the rest of the organisation.

The lack of isolation of the project team is also indicated by the IPMA standard, according to which the project manager should act in such a way that project management is linked to the organisation's business administration. In addition to this, he or she should coordinate project activities in line with the organisation's objectives and characteristics, taking into account its needs, culture and management processes. This is because the compatibility between the project and the permanent organisation is intended to help attract resources to the project, which will not be possible if the members of the organisation do not accept the functioning of the project team.

Similarly, according to PMI or agile methodologies, project management processes should be configured according to the specific characteristics and needs of the organisation as the way a project is implemented is also influenced by the factors related to the organisation

implementing the project. While PRINCE2 offers a more formalised management and reporting structure, which ensures systematic communication and stakeholder engagement, reducing the risk of project team isolation, PMI relies on flexibility, adaptation and strong communication and stakeholder management. Teams are more dynamic and adapt their practices according to the needs of the project and the environment. Ultimately, Agile methodologies are designed to minimise team isolation through continuous collaboration, frequent meetings and regular stakeholder engagement. Compared to PMI and PRINCE2, Agile offers more intensive and daily interaction, which effectively counteracts the isolation of the project team and allows project management methods to be tailored to project realities.

The analysis of the above-mentioned methodologies indicates that also in the case of highly innovative projects, the isolation of the project team is considered undesirable. In such projects, in which innovation and creativity are key, collaboration, communication and involvement of all team members and stakeholders are even more important. This results partially from that fact that the lack of isolation of the project team:

- fosters synergy and diversity of thinking; in innovative projects, it is crucial to draw on diverse perspectives and skills to generate new ideas and solutions;
- enables dynamic adaptation and rapid response; innovative projects often require rapid adaptation to changing conditions and technologies. Regular communication and close team collaboration allow problems to be identified more quickly and necessary changes to be made;
- stimulates creativity; isolation can inhibit creativity as team members may not have access to inspiration and ideas from others. Collaborating and exchanging ideas openly foster creativity and innovation in projects;
- enables support for innovation through stakeholder management; stakeholder engagement at different stages of a project can provide valuable feedback and perspectives that can be crucial to the success of innovative ventures. Regular reporting and communication with stakeholders also help to quickly identify and respond to changing market and technology needs.

To sum up, it is inappropriate to isolate project teams in highly innovative projects as this limits the possibilities for synergy, creativity or dynamic adaptation. Teams should work in an environment that fosters collaboration, open communication and active stakeholder engagement in order to achieve success. In doing so, assuming that project success in the methodologies cited above refers to all the project dimensions mentioned (i.e., both the triple constraint and the long-term view), the following research hypothesis H1 can be formulated: Hypothesis H1 – The less isolated the team implementing a highly innovative project is, the greater the extent to which both the short-term and long-term objectives of the project are achieved.

4. Preparing for the future and isolating highly innovative projects

In the case of preparing for the future, reference can be made to the resource approach in strategy formulation, which is based on the observation that only those organisations are sustainably competitive that have special basic or core competences. They do not refer to one market or one domain but are permeable in nature and can be applied to different domains and especially to future markets (Hamel, Prahalad, 1999). One of the most vital features of core competences is the way of their creation, which is not stuck in the material aspects of the resources. This is because core competences result from team learning or long-term innovation processes and are therefore not individually assimilable (Steinmann, Schreyögg, 2001; Moszkowicz, 2001; Chrupała-Pniak, Sulimowska-Formowicz, 2010). Thus, if new norms and values, which differ from the existing organisational culture, are developed in a project team carrying out an innovative project (Kamiński, 2021), then, in particular, norms and values that are new or that challenge the *status quo* will enrich the organisation. They may prove to be essential for the organisation to operate in new and unpredictable conditions. The necessity of developing new and even contradictory norms and values for the sake of maintaining competitive advantage was discussed in *Leading the Revolution* by Hamel (2001). In it, he describes innovations that do not pertain to new products or new technologies but to new entrepreneurial models. Following Hamel, this kind of innovation is the source of the most important competitive advantage in the current century. He defines them as discontinuous innovation as opposed to continuous innovation, which is merely an improvement of an existing product or service. Discontinuous innovation concerns entire innovative business concepts. As examples, he cites companies that break with the previous rules of competition in an industry and adhere to the principles of formulating revolutionary visions, which means endorsing intuition as well as supporting differently thinking and thought-provoking heretics (who show and overturn dogmas and constantly ask why). These contradictions create the so-called tension, which, according to Martin and Behrends (1999), belongs – alongside loose coupling and organisational slack – to the basic tenets of innovation. This tension is either triggered by changes in the environment or is the result of intra-organisational contradictions. Changes in the environment involve a discrepancy between the expected (and intended) and actual responses of the (changing) environment. Changing organisational conditions, therefore, force learning processes and can give rise to innovation. Moreover, intra-organisational contradictions arise from the different preferences and beliefs of the members of the organisation as they often operate in different sub-systems of the organisation and the problems that arise on a daily basis have many potential solutions. The different viewpoints of the members of the organisation thus developed lead to contradictions during decision-making, which – if properly exploited – can be a source of innovative solutions.

Many practical examples of such innovative solutions are described, among others, in *The Future of Management* by Hamel and Breen (2007). When traditional management models based on hierarchy, control and predictability are outdated in the face of today's market challenges, they need to adopt a more flexible, innovative and collaborative management approach to survive and thrive in today's rapidly changing business environment. As Dvir and Shenhar (2011) point out, innovative projects can be the source of new management models. As examples, they cite Boeing's collaboration with carriers and supplier networks in the project to build the Boeing 777 and the design of the BMW Z3, a stylish roadster developed by the BMW Group in the early 1990s. Another example is Chrysler (Dodge's parent company), which used an out-of-the-box approach to manage the project to build the Dodge Viper (Rose, 2023; Boyd, 2024). Key elements included a small, autonomous engineering team, rapid decision-making, minimal bureaucracy and an emphasis on innovation and rapid implementation. This approach helped to create a car that has become iconic while reducing the time of launching it on the market. In the case of the Dodge Viper, much of the development work was transferred to suppliers. Chrysler followed an approach in which key components, such as the engine and other essential components, were developed in collaboration with external suppliers. This allowed the company to shorten the time of launching the product on the market and reduce costs while benefiting from the expertise and innovation of partners (such as Lamborghini). This approach of transferring part of the development work to suppliers is widely used today in the automotive industry and beyond. Given the above, those projects transformed the way the entire organisation, sector and even the industry operates.

To sum up, preparing for the future on the basis of norms and values which are new or different from the binding ones fosters the development of the so-called strategic flexibility, which is defined as: "[...] the ability of an organisation to identify major changes in the external environment, to quickly allocate resources to new courses of action in response to those changes and to recognise and act quickly in a timely manner so as to pause or undo existing commitments of corporate resources" (Shimizu, Hitt, 2004, p. 45). On the one hand, strategic flexibility, understood in this way, leads to competitive advantage in a rapidly changing and increasingly uncertain environment (Eryesil et al., 2015). The lack of strategic flexibility, on the other hand, stems from the common routines and taken-for-granted thinking and decision-making principles of top management. Ideas and actions that deviate from existing procedures are not adopted, resulting in organisational inertia and reducing the likelihood that new information will be brought to the attention of the organisation. Instead, it is ignored or considered an exception to the rule and no one analyses it further.

In the context of the above, it is not surprising that many authors tend to isolate innovative ventures so that there is the possibility of developing intra-organisational contradictions. Thus, for example, Trocki (2009), for the implementation of large and highly innovative projects, recommends the so-called "pure" project organisation, in which a separate project team has the resources necessary to implement the project and has implementation capabilities

beyond the scope of the organisation's existing competences, which provides the potential for new experiences and learning.

Similarly, the need for offering freedom during implementation in innovative projects is pointed out by Hammer (1998) and Wozniak (Wozniak, Łokaj, 2009). Hammer notes that if organisations operate on the basis of paternalism, use extensive control mechanisms, are bureaucratic and target personal freedom, then all invention is lost in the maze of formal company rules and creative thinking can rather only be developed outside working hours. In the interview, Wozniak, a co-founder of Apple Inc., talks "about a small garage on the sidelines of the corporation". In his view, corporate culture can hinder the development of ideas and a group of innovators should not be located too deep in the organisational structure. It means that they should not have too many hierarchical levels, superiors and decision-making dependencies above them. Organisational executives need to understand that true innovation, which brings things so new that they are called revolutionary, almost always arises not in the company but at home – it is created by young people who often work in their garage. This is why highly innovative organisations provide their employees with 20% of their working time to independently develop their own ideas and projects.

What is more, in the strategic management literature, one can point to studies by Utterback (1994), Bower and Christensen (1995) or Benner and Tushman (2003). According to Utterback, well-established companies can gain a foothold in markets shaped by radical technological innovation by creating autonomous, independent units to harness the organisational flexibility and entrepreneurial spirit needed to succeed in the new environment. IBM, for example, successfully entered the PC market through a separate, dedicated unit set up far from the company's headquarters. Likewise, both Ford Motor Company and General Motors formed separate entities (Team Taurus and Saturn Motor Company, respectively) to market their new car models. The task of creating the competences needed to successfully enter selected markets depended on creating organisations with a high degree of independence from the staff, committees and other burdens of their parent companies. Bower and Christensen (1995) were the first to introduce this idea into the literature on business model innovation. They suggested that the functioning company should place the responsibility for building groundbreaking businesses in an independent organisation by creating teams in skunkworks projects to keep them away from the core business. By isolating, they said, a company can avoid any potential negative influences from organisational culture, policies and systems that could hinder new business development. Finally, it should not be forgotten that also Benner and Tushman (2003), in their study on ambidextrous organisation, concluded that experimentation and groundbreaking innovation should be separated organisationally and that what should be set up is the organisational units focused only on this activity.

To conclude this part, it is worth stating that isolating innovative projects from the core of the organisation is conducive to their more effective development and implementation as it protects them from the influence of the existing organisational culture, bureaucratic procedures

and routine ways of thinking that can inhibit important creativity and innovation in terms of preparing for the future. One may get the impression that the emphasis is, therefore, primarily on learning and that short-term issues are secondary. Thus, in the context of the above considerations and the literature references cited, the following research hypothesis H2 can be formulated: Hypothesis H2 – The more isolated the team executing a highly innovative project, the more the norms and values that prepare the organisation for the future are developed – the long-term objectives of the project are achieved.

5. Verification of research hypotheses

The empirical verification of the research hypotheses will be carried out on the basis of surveys. The research tool is a questionnaire while statistical methods are used to analyse the empirical data. Thus, for research hypothesis H1, the fulfilment of the project objectives, budget and timetable was assessed to measure the extent to which the short-term objectives of the project were achieved based on the opinion of the project manager. Moreover, when measuring the extent to which long-term project objectives were achieved (hypotheses H1 and H2), the cultural metaphor of the organisation was used, according to which organisations can be treated as cultures. They can be considered socially conditioned both at the level of social groups, ties, power mechanisms and communication as well as at the level of their products, i.e., values, norms and social patterns. Such an analogy is developed in the organisational culture and cross-cultural management strand (Sułkowski, 2004). In such a metaphor, the project team will have their own norms and values and can be regarded as an organisational subculture whose norms and values will be all the more different from the organisational culture, the more intensive the learning within the project team is. This is because the project team, when carrying out an innovative project, will have to create and verify new ways of doing things that can prepare the organisation for the future (Kamiński, 2021). This is in line with, among others, the views of Schein (2017), according to whom organisational culture is the result of learning while solving problems of external adaptation and internal integration.

Given the above, in order to assess the organisation's preparation for the future, it was decided to calculate Kendall's tau-b correlation coefficient between the different dimensions of culture in the organisation and in the project team. It was assumed that in the case of:

- the positive value of the correlation coefficient along with the increase in the intensity of a dimension in the organisational culture, the intensity of that dimension in the project team will also increase – the norms and values developed in the project team are in line with the existing organisational culture and the organisation is not preparing for the future in this way,

- the negative value of the correlation coefficient along with the increase in the intensity of a dimension in the organisational culture, the intensity of this dimension in the project team will decrease – the norms and values developed in the project team are not in line with the existing organisational culture, they question the *status quo*, which means that, as a result of the project implementation, the organisation is preparing for the future,
- the zero value of the correlation coefficient, changes in the intensity of a given dimension in organisational culture are not linked in any way to changes in that dimension in the project team – other norms and values, neither conflicting nor confirming the existing organisational culture, are created. The existing organisational culture is thus enriched with something new, which prepares it for the future.

Seven dimensions of organisational culture were used to measure norms and values, consisting of (Hopkins et al., 2005): employee autonomy, formalisation of activities, support of ubordinates by the supervisor, identification of employees with either the project or the organisation, performance awards, acceptance of conflicts between employees or teams and acceptance of risk.

The study included companies whose core business was repetitive and which had project teams using classic project management methodologies (e.g., PRINCE2, PMI, IPMA). The main reasons for selecting the traditional project management approach were identified as being, first and foremost, clearly defined project objectives, a well-defined organisational structure or the restrictiveness of management in terms of how key project processes are carried out (cf., e.g. Wyrozębski, 2007; Kopczynski, 2014). Therefore, the questionnaire was addressed to project managers of different organisations (taking into account the industry as well as organisation size and ownership form). However, only the information from the questionnaires meeting the above-mentioned limitations was used to verify the hypotheses. The research subjects were organisations operating in Europe and the USA. The study was conducted between December 2019 and January 2020. Results were obtained from 106 project managers from organisations operating in Europe and 281 from those functioning in the USA, which gave a total of 387 questionnaires. Next, 98 questionnaires describing projects that were identified by the respondents as ground-breaking based on the levels of project innovation defined by Shenhar and Dvir (2008) were selected.

Thus, research hypothesis H1 considers the relationship between the extent to which the project team interacts with the rest of the organisation and:

- the achievement of short-term project objectives and
- the correlation coefficient between the norms and values found in the project team and the norms and values of organisational culture.

Hypothesis H2 only considers the relationship between how much the project team's interaction with the rest of the organisation is fostered and the correlation coefficient between the norms and values found in the project team and the norms and values in organisational culture.

Finally, the status of the project in the organisation, the dependence of project team members on working for the project team (understood as receiving remuneration for their work on the project, tying their career to their work on the project, the length of time spent working for the project team) and the number of communication methods used in the project were considered to be factors fostering interaction. These three factors were aggregated to a single variable and two ranges of its values were identified to characterise innovative projects where either the project team's interaction with the rest of the organisation was fostered or not. The observations collected in the surveys were assigned to these two ranges. The degree to which the project short-term objectives were met was calculated; it is presented in Table 1. Moreover, the correlation coefficients were calculated – they are presented in Table 2.

Table 1.
Fostering interaction between the project team and the rest of the organisation and the degree of achievement of short-term project objectives

Short-term objective of the project	**Degree of implementation**	**Interactions are not fostered**		**Interactions are fostered**	
		n = 35		n = 63	
Scope of the project (level of the achievement of the defined deliverables)	none implemented	2	5.7%	0	0,0%
	some	3	8.6%	7	11.1%
	most	16	45.7%	21	33,3%
	all	14	40,0%	**35**	**55.6%**
Project budget	significantly exceeded	4	11.4%	9	14.8%
	slightly exceeded	9	25.7%	13	21.3%
	100% implementation	11	31.4%	**24**	**39.3%**
	lower project costs than anticipated	11	31.4%	15	24.6%
Project timetable – implementation time	significantly exceeded	11	31.4%	10	15.9%
	slightly exceeded	13	37.1%	24	38.1%
	in line with the target	10	28.6%	**20**	**31.7%**
	shorter than anticipated	1	2.9%	9	14.3%

Source: The author's own study.

Table 2.
Fostering interaction between the project team and the rest of the organisation and the development of norms and values that prepare the organisation for the future

Dimensions of culture	**Interactions are not fostered**	**Interactions are fostered**
	n = 35	n = 63
	Correlation coefficient	Correlation coefficient
Employee autonomy	0.446*	0.364**
Degree of formalisation of activities	0.425*	0.336**
Support provided to subordinates	0.276*	0.323**
Identification with the organisation/project team	0.201*	0.193*
Performance awards	0.457*	0.319**
Acceptance of conflicts	0.465*	0.286*
Acceptance of risk	0.255*	0.437**

* Correlation is significant at the level of 0.05 (in both directions).
** Correlation is significant at the level of 0.01 (in both directions).

Source: The author's own study.

The results presented in Table 1 and Table 2 indicate that both research hypotheses H1 and H2 were not confirmed. However, it should be noted that part of hypothesis H1 has been confirmed, namely that the lack of isolation of highly innovative projects is linked to the achievement of short-term project objectives. If projects were not isolated, they were more likely to have fulfilled their scope and were more likely to be within budget and on time. Moreover, the norms and values within the project team correlate positively with those of organisational culture, indicating that new ways of doing things or challenging the *status quo* are not being developed. Thus, while the recommendations made in project management standards and methodologies have been validated on the basis of empirical research, the findings of the innovation and strategic management literature have not been validated using the selected research method.

6. Conclusions

Empirical findings have shown that fostering the project team's interaction with the rest of the organisation is linked to the achievement of short-term project objectives. Thus, as highlighted in the literature (Hoegl, 2008; Willems et al., 2020), this may be due, firstly, to easier exchange of information as the project team can obtain information from other departments in the organisation, which allows for a better understanding of the context, requirements and potential challenges of the project and a well-informed team can make more accurate decisions. Secondly, regular interaction with the rest of the organisation helps to build support for the project. When other employees feel involved or aware of the project progress, they are more likely to provide assistance when the project team needs it. Thirdly, it is also possible to manage resources more efficiently when projects require resources from different parts of the organisation, such as equipment, data, expertise or personnel. Good relationships and regular communication with the rest of the organisation facilitate access to these resources. Fourthly, various obstacles may arise during the course of a project. They may require a quick response and cooperation with other departments. Regular interaction enables problems to be identified quickly and solutions to be worked out together. Fifthly, working closely with other departments in the organisation helps to understand their objectives and priorities. This enables the project team to better align their activities to be consistent with the overall objectives of the organisation, minimising the risk of conflicts. Finally, sixthly, regular interaction helps the project team to become more integrated into organisational culture, which promotes better collaboration and understanding of internal processes. This can lead to a smoother project implementation and a better fit with the expectations of the organisation. Therefore, these arguments seem to outweigh – at least for the projects examined – the arguments put forward by proponents of isolating innovative projects.

The latter aspect, the compatibility of the project team's norms and values with organisational culture, manifests itself in positive values of the correlation coefficients. This means that if, for example, a high degree of employee autonomy is fostered in an organisation, project team members will also have a relatively high degree of autonomy when implementing projects. However, if risks are avoided in the organisation, risks will not be accepted in project implementation either. The degree of the formalisation of activities or the leadership style of employees will also be shaped similarly. Thus, on the basis of the results obtained, it can be concluded that, while organisations should treat each of their projects as an individual endeavour that is different from others, in this case, in terms of innovation, the way a project is implemented is strongly influenced by the organisation, in which that project is embedded, and its culture. The prevailing view that an organisation's project world will be associated with an entirely different management approach does not hold true in this case. This may be due to the need to – at least partially – embed project management approaches in the organisation's existing management systems and technologies used, the personnel policy practised, health and safety regulations, financial management approaches or the regulations observed. This compatibility will, on the one hand, promote the achievement of the project objectives. As might be assumed, compatibility will help to achieve the scope of the project and not necessarily or only secondarily to ensure its efficiency. This may be because the solutions used are a certain compromise between design and organisation. On the other hand, the alignment of norms and values will counteract the project-induced disruption to the delivery of an organisation's core business.

The research carried out obviously has its weaknesses, which include, first and foremost, a focus on organisations whose *core business* involves repetitive activities rather than unique projects. This may mean that the answer to the question whether innovative projects should be isolated depends on the nature of the organisation in which the project is implemented. It is, therefore, reasonable to ask whether innovative projects should also be isolated in the case of an innovative organisation. Indeed, it can be seen in business practice that isolating the team implementing an innovative project in an innovative organisation is also justified and has certain strengths (Kamiński, Rosłoń, 2023).

References

1. Atkinson, R. (1999). Project Management: Cost, Time and Quality, Two Best Guesses and a Phenomenon, its Time to Accept Other Success Criteria. *International Journal of Project Management*, *Vol. 17, Iss. 6*, pp. 337-342, doi: 10.1016/S0263-7863(98)00069-6.
2. Baker, B.N., Murphy, D.C., Fisher, D. (1988). Factors Affecting Project Success. In: D.I. Cleland, W.R. King (Eds.), *Project Management Handbook* (pp. 902-919). Second Edition. New York: Wiley.
3. BCG (2023). *The CEO Outlook. Caution, Optimism, and Navigating the Road Ahead*. Retrieved from: https://media-publications.bcg.com/BCG-Executive-Perspectives-CEO-Outlook-Survey-March-2023.pdf, 1.09.2024.
4. Benner, M., Tushman, M. (2003). Exploitation, Exploration, and Process Management: The Productivity Dilemma Revisited. *The Academy of Management Review*, *Vol. 28*, *No. 2*, pp. 238-256, doi: 10.5465/AMR.2003.9416096.
5. Bower, J.L., Christensen, C.M. (1995). Disruptive technologies: Catching the wave. *Harvard Business Review, January, Vol. 73*, pp. 43-53.
6. Boyd, J. (2024). *The History of the Dodge Viper*. Retrieved from: https://autotrends.org/dodge-viper-history/, 1.09.2024.
7. Chan, A.P.C., Scott, D., Lam, E.W.M. (2002). Framework of Success Criteria for Design/Build Projects. *Journal of Management in Engineering*, *Vol. 18, Iss. 3*, pp. 120-128, doi: 0.1061/(ASCE)0742-597X(2002)18:3(120).
8. Chrupała-Pniak, M., Sulimowska-Formowicz, M. (2010). Organizacyjna kompetencja innowacyjności: determinanty psychospołeczne i ekonomiczne. *Chowanna*, *Vol. 2*, pp. 119-144.
9. Dvir, D., Shenhar, A. (2011). What great projects have in common. *IEEE Engineering Management Review*, *No. 52*, pp. 19-21, doi: 10.1109/EMR.2015.7433290.
10. Eryesil, K., Esmen, O., Beduk, A. (2015). The role of strategic flexibility for achieving sustainable competition advantage and its effect on business performance. *World Academy of Science, Engineering and Technology*, *Vol. 9*, *No. 10*, pp. 587-593, doi: 10.5281/zenodo.1109381.
11. Galbraith, J.R. (1999). Projektowanie organizacji innowacyjnej. In: P.F. Schlesinger, V. Sathe, L.A. Schlesinger, J. Kotter (Eds.), *Projektowanie organizacyjne* (pp. 95-118). Warszawa: PWN.
12. Griffin, A. (1997). The Effect of Project and Process Characteristics on Product Development Cycle Time. *Journal of Marketing Research, Vol. 34*, *Iss. 1*, pp. 24-35, doi: 0.2307/3152062.
13. Hamel, G. (2001). *Leading the Revolution*. Boston, Mass.: Harvard Business School Press.

14. Hamel, G., Breen, B. (2007). *The future of management*. Boston, Mass.: Harvard Business School Press.
15. Hamel, G., Prahalad, C.K. (1999). *Przewaga konkurencyjna jutra*. Warszawa: Business Press.
16. Hammer, M. (1998). Dusza nowej organizacji. In: F. Hesselbein, M. Goldsmith, R. Beckhard (Eds.), *Organizacja przyszłości* (pp. 41-47). Warszawa: Business Press.
17. Hoegl, M. (2008). *Teamwork and innovation. Paper presented at PMI® Research Conference: Defining the Future of Project Management, Warsaw, Poland*. Newtown Square, PA: Project Management Institute.
18. Hopkins, W.E., Hopkins, S.A., Mallette, P. (2005). *Aligning organizational subcultures for competitive advantage: A strategic change approach*. New York, NY: Basic Books.
19. Jugdev, K., Müller, R. (2005). A retrospective look at our evolving understanding of project success. *Project Management Journal*, *Vol. 36*, *Iss. 4*, pp. 19-31, doi: 10.1177/875697280503600403.
20. Kamiński, R. (2021). *Subkultura zespołu projektowego*. Wrocław: Oficyna Wydawnicza Politechniki Wrocławskiej.
21. Kamiński, R., Rosłoń, R. (2024). A small garage on the sidelines of a corporation: Should innovative projects be isolated? *Ekonomia*, *Vol. 29*, *No. 3*, pp. 7-17, doi: 10.19195/2658-1310.29.3.1.
22. Kiełbus, A. (2011). Zarządzanie innowacyjnymi projektami IT w odniesieniu do tradycyjnego zarządzania projektami. *Czasopismo Techniczne. Mechanika*, *Vol. 108*, *Iss. 7*, pp. 219-226.
23. Klaus-Rosińska, A. (2019). *Sukces projektów badawczych i badawczo-rozwojowych w sektorze nauki*. Wrocław: Oficyna Wydawnicza Politechniki Wrocławskiej.
24. Kopczyński, T. (2014). Rola i kompetencje kierownika projektu w zwinnym zarządzaniu projektami na tle tradycyjnego podejścia do zarządzania projektami. *Studia Oeconomica Posnaniensia*, *Vol. 2*, *No. 9*, pp. 101-114.
25. Martin, A., Behrends, T. (1999). Die Innovative Organisation aus kultutheoretischer Perspektive. In: *Schriften aus dem Institut für Mittelstandsforschung*, *No. 10.* Lüneburg: Universität Lüneburg, Institut für Mittelstandsforschung.
26. Moszkowicz, K. (2001). *Procesy innowacyjne w polskim przemyśle*. Wrocław: Wydawnictwo Akademii Ekonomicznej im Oskara Langego we Wrocławiu.
27. Office of Government Commerce (OGC). (2010). *Skuteczne zarządzanie projektami PRINCE2™*. Warszawa: CRM S.A.
28. Pinto, J.K., Slevin, D.P. (1988). Project success: Definitions and measurement techniques. *Project Management Journal*, *Vol. 19*, *No. 1*, pp. 67-73.
29. Rose, Ch. (2023). *The history and legacy of the Dodge Viper*. Retrieved from: https://americansupercars.com/dodge-viper-history/, 1.09.2024.
30. Schein, E.H. (2017). *Organizational culture and leadership*. Hoboken, NJ: Wiley.

31. Shenhar, A.J., Dvir, D. (2008). *Nowe spojrzenie na zarządzanie projektami*. Warszawa: APN Promise.
32. Shenhar, A.J., Dvir, D., Levy, O., Maltz, A.C. (2001). Project success: A multidimensional strategic concept. *Long Range Planning*, *Vol. 34*, *Iss. 6*, pp. 699-725, doi: 10.1016/S0024-6301(01)00097-8.
33. Shimizu, K., Hitt, M. (2004). Strategic flexibility: Organizational preparedness to reverse ineffective strategic decisions. *Academy of Management Executive*, *Vol. 18*, *No. 4*, pp. 44-59, doi: 10.5465/AME.2004.15268683.
34. Steinmann, H., Schreyögg, G. (2001). *Zarządzanie – podstawy kierowania przedsiębiorstwem. Koncepcje, funkcje, przykłady*. Wrocław: Oficyna Wydawnicza Politechniki Wrocławskiej.
35. Sułkowski, Ł. (2004). Metafory w życiu organizacji. *Przegląd Organizacji*, *No. 6(773),* pp. 7-10, doi: 10.33141/po.2004.06.01.
36. Trocki, M. (2009). *Organizacja projektowa*. Warszawa: BIZARRE.
37. Trocki, M. (2012). *Podstawy zarządzania projektami*. Warszawa: PWE.
38. Utterback, J.M. (1994). *Mastering the dynamics of innovation*. Boston: Harvard Business School Press.
39. Westerveld, E. (2003). The project excellence model: Linking success criteria and critical success factors. *International Journal of Project Management*, *Vol. 21, Iss. 6,* pp. 411-418, doi: 10.1016/S0263-7863(02)00112-6.
40. Willems, T., Marrewijk, A.H., Kuitert, L., Volker, L., Hermans, M. (2020). Practices of isolation: The shaping of project autonomy in innovation projects. *International Journal of Project Management*, *Vol. 38*, *Iss. 4*, pp. 215-228, doi: 10.1016/j.ijproman.2020.03.004.
41. Wit de, A. (1988). Measurement of project success. *International Journal of Project Management*, *Vol. 6*, *Iss. 3*, pp. 164-170, doi: 10.1016/0263-7863(88)90043-9.
42. Wozniak, S., Łokaj, A. (2009). Mały garaż na uboczu korporacji. *Magazyn HBRP*, *Vol. 82/83, grudzień-styczeń*.
43. Wyrozębski, P. (2007). Elastyczne podejście do zarządzania projektami. In: S. Lachiewicz, M. Matejun (Eds.), *Problemy współczesnej praktyki zarządzania* (pp. 151-152). Łódź: Wydawnictwo Politechniki Łódzkiej.
44. Zgrzywa-Ziemak, A., Kamiński, R. (2009). *Rozwój zdolności uczenia się przedsiębiorstwa*. Warszawa: Difin.

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ON TIME TO BUFFER OVERFLOW IN A PROCESSING MODEL WITH PERIODIC SUSPENSION OR SERVICE SLOWDOWN

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Purpose: Contemporary challenges related to the need for energy savings and optimization determine the design of service systems (computer and telecommunications networks, production systems, logistic centers, transport solutions, etc.) equipped with appropriate mechanisms supporting the reduction of their operating costs and optimizing the use of available sources and machines. On the other hand, it is essential to maintain the highest quality of service (QoS) for the developing system as much as possible simultaneously.
Designing/methodology/approach: The study employs a queueing-theory-based model to analyze a FIFO-type finite-buffer service system with an embedded optimization mechanism. The primary goal is to balance energy savings and service quality (QoS) in computer networks, telecommunications, production systems, and logistics.
Findings: An explicit Laplace transform representation is derived for the time to first buffer overflow, based on the initial system state. The methodology allows calculating the mean time to buffer overflow for any starting condition.
Originality/value: In the paper, we propose a queueing-theory-based model of the FIFO-type finite-buffer service system in which an optimization algorithm is implemented. Namely, every time the system becomes empty whenever the server chooses either to go on a vacation, during which the processing is blocked completely or to reduce the service intensity temporarily. For a model with a Poisson-type input stream and generally distributed service time and vacation duration, we obtain the explicit formula for the Laplace transform of the time to the first and next buffer overflows conditioned by the accumulating buffer state at the beginning of an appropriate busy period. Hence the mean duration of such times can be found as well.
Keywords: Working vacation, stochastic processes, mathematical modeling.
Category of the paper: Research paper.

1. Introduction and Motivation

Currently, many papers are available regarding queueing models and their applications to real-life problems. The literature still grows fast, and more complex models are analyzed in different settings to solve problems that arise due to the fast development of technology. From the perspective of computer networks, telecommunication, and production systems, today, one of the most critical problems is reducing energy consumption to keep operating costs low.

One way to keep power consumption low is to stop processing the arriving jobs temporarily. This method has been studied for years and is still one of the main energy-consumption reduction approaches. To prevent the system from switching the state often, which may lead to higher energy consumption when extra energy is needed to turn the server on, or to a higher maintenance cost due to the more excellent wear of the server components, the so-called N-policy can be applied, see, e.g. (Kempa et al., 2010), where the queue length for batch arrival model with N-policy and setup times were considered. The energy-saving capability of the sleep mode was analyzed, e.g., in (Chunxia, Shunfu, 2018; Yin et al., 2020; Yin et al., 2022), where the queueing model was used to model the virtual machine sleep schedule; in (Kempa, 2019), where the vacation queue with N-policy was used to model the Wireless Sensor Network node, in (Harini, Indhira, 2024), where the queueing model with vacation was used to analyze a 5G base station, or in (Jin et al., 2020), where vacation queue with N-policy was considered to save energy in cloud data center.

Unfortunately, applying the sleep mode can lead to a decrease in the quality of service. When the jobs are not processed, they accumulate in the buffer, and due to the finite capacity of the real-life systems, they can be lost when the buffer is saturated. To help reduce the negative impact of completely turning the server off, the working vacation mode can be introduced instead of the vacation mode. In working vacation (or so-called semi-sleep, semi-vacation) mode, the server processes the jobs at reduced speed instead of closing entirely for the arriving customers. In Zhu et al. (2004), Bostoen et al. (2013), one can find the justification for using the working vacation mode as an energy-saving mechanism in the context of cloud data centers and real-time embedded systems. The queue with working vacation policy was considered, for example, in Qin et al. (2019), where this policy was applied to conserve energy on the cloud platform, or in Gong et al. (2020), where the working vacation model with N-policy was used to improve the cost-performance ratio in cyber-physical systems.

Recently, many researchers have considered models with a mixed vacation and working vacation policy. In Jin et al. (2019), a model with two service speeds and vacations was used to model a cloud data center. Based on the state, virtual machines are put into sleep mode or slow down the service. In Ait Braham et al. (2023), two types of vacations are implemented. When the system becomes empty, it takes a type I vacation at random times, and if at the end

of the type I vacation, no jobs are waiting, it takes a type II vacation. A similar solution was described in Mohammed Shapique et al. (2024), where the energy-saving capability of this approach is analyzed in the context of WiMAX and tethered high-altitude platform systems. In Divya, Indhira (2024), the cost analysis of the hybrid vacation policy is performed. As one can note, vacation and working vacation are usually used to model servers that can enter more than one successive vacation period. In the following periods, the type of vacation can change. Sometimes, a different approach would be of great value to better reflect the behavior of the modeled system.

This paper considers the finite buffer queueing model with Poisson arrivals and general service times. When the system empties, it changes its operating mode to vacation mode, when no jobs are processed, or to working vacation mode, when jobs are processed but at lower speed. The operating mode is chosen randomly, which may reflect, for example, a system where some background tasks need to be done. The server waits until there are no main tasks to do and then moves some resources to work on secondary tasks, which results in a slower speed of processing main tasks if they appear during this period. When there are no side jobs to be done, the server goes to sleep mode.

The paper is organized as follows. In Section 2, a detailed description of the model is given. In Section 3, the system of integral equations for the transient time to the first buffer overflow is stated and solved in terms of the Laplace transform in Section 4. The Theorem summarizing the result is given with an additional result for the mean time to the first buffer overflow. In Section 5, the instructions to obtain the distribution to k-th buffer overflow are given for $k = 2,3, \ldots$. The mean time to the k-th buffer overflow is also presented.

2. Model description

In this section, we give a detailed description of the service model considered and introduce the necessary notation. Let us consider a single-server queueing model in which messages arrive according to a simple Poisson process with constant rate $a > 0$ and are processed individually, according to a FIFO service rule. A processing time of an individual message is randomly distributed with a cumulative distribution function (CDF) $F(\cdot)$. A message departs the system immediately after its processing is completed. An arriving message that finds the server busy with processing joins the queue and waits for service. An accumulation buffer (waiting room) has a predefined capacity. Hence, the maximum system size equals B, namely $B - 1$ places are available in the buffer, and one spot is reserved for the message being processed. Consequently, if the entering message finds the system saturated (the server is busy with processing and all places in the buffer are occupied) it is lost due to buffer overflow.

Every time when the system empties (at the service completion epoch of the message that leaves the system empty), the optimization mode is being started. Namely, either the service station becomes unavailable for a certain period of time of random length (server vacation), or when a message enters the empty system, its service is started, but its duration has a CDF $F^{\star}(\cdot)$ and with probability one lasts at least as long as in the case of other customers (service slowdown), so we have:

$$F^{\star}(t) \leq F(t) \tag{1}$$

for each $t > 0$.

The choice of one of the two above options is determined by the value of the parameter $\gamma \in [0,1]$. More precisely speaking, with probability γ the server goes to the vacation which is randomly distributed with a CDF $V(\cdot)$. During the vacation, the processing of messages is completely blocked. Otherwise, however, the server with probability $1-\gamma$chooses the option of the service slowdown. In this case, the server is always ready to process, but the first message incoming to the empty system is served "longer" than other messages.

The above-described mechanism of temporary suspension or slowing down of service allows for practical modeling of a real system in which the optimization mechanism has been implemented. The server handles secondary tasks when there are no messages in the system. If these tasks are large, the server chooses to suspend the handling of primary functions for some time entirely. When the number of secondary tasks is small, the server does not suspend the handling of primary tasks. Still, while the first one is being handled, it simultaneously ultimately finalizes handling secondary tasks. Of course, the period of suspension or slowing down of service can also be used to perform a periodic server inspection or update the appropriate IT system.

Let us denote by $N(t)$ the number of messages (jobs, customers, packets, etc.) present in the system at time $t \geq 0$, including the one being processed at this time, if any.

Besides, let δ_k, $k = 1,2,\ldots$, stands for the time to the kth buffer overflow, so the length of the time period between the completion epoch of the $(k-1)$th busy period of the system and the first moment after this time at which the system becomes saturated (the number of messages present equals B). Obviously, δ_1 represents the time from the opening of the system at $t = 0$ to the first overflow occurrence, so we denote:

$$\delta_1 \stackrel{def}{=} \min\{t > 0 : N(t) = B\}. \tag{2}$$

3. Integral Equations for the Time to the First Buffer Overflow

In this section, we derive the system of integral equations for the tail probability distribution of the time δ_1 to the first buffer overflow, conditioned by the state of the accumulation buffer at the starting epoch $t = 0$.

Introduce the following notation:

$$D_n(t) \stackrel{def}{=} \mathbf{P}\{\delta_1 > t \mid N(0) = n\}, \tag{3}$$

where: $n \in \{0, \ldots, B-1\}$ and $t > 0$.

Assume firstly that the buffer is empty at the opening of the system ($t = 0$). Evidently, in this case the server can choose either going for a vacation or processing with a slower speed. Observe that in such a case, to have a non-zero probability that $\delta_1 > t$, the following mutually excluding random events can occur for fixed $t > 0$:

- $\mathbb{A}_1(t)$: the server goes for a vacation that finishes before time t and the first message arrives after the vacation completion but still before t;
- $\mathbb{A}_2(t)$: the server goes for a vacation that finishes before time t with k messages present, where $k \in \{1, \ldots, B-1\}$;
- $\mathbb{A}_3(t)$: the server goes for a vacation that finishes after time t and the number of messages accumulated in the buffer at time t equals k, where $k \in \{1, \ldots, B-1\}$;
- $\mathbb{A}_4(t)$: the server chooses slowing down the service and the first message enters before t;
- $\mathbb{A}_5(t)$: the first message occurs after time t.

The formula of total probability gives:

$$D_0(t) = \sum_{i=1}^{5} D_0^{(i)}(t), \tag{4}$$

where:

$$D_0^{(i)}(t) \stackrel{def}{=} \mathbf{P}\{\delta_1 > t, \mathbb{A}_i(t) \mid N(0) = 0\}. \tag{5}$$

It is easy to check that the following representation is true, considering the random event $\mathbb{A}_1(t)$:

$$D_0^{(1)}(t) = \gamma \int_0^t a e^{-ax} V(x) D_1(t-x) dx. \tag{6}$$

Similarly, for $\mathbb{A}_2(t)$ we get:

$$D_0^{(2)}(t) = \gamma \int_0^t \sum_{k=1}^{B-1} \frac{(ay)^k}{k!} e^{-ay} D_k(t-y) dV(y). \tag{7}$$

For the random event $\mathbb{A}_3(t)$ we obtain the following expression:

$$D_0^{(3)}(t) = \gamma \overline{V}(t) \sum_{k=1}^{B-1} \frac{(at)^k}{k!} e^{-at}. \tag{8}$$

where: $\overline{V}(t) \overset{def}{=} 1 - V(t)$.

In the case of the random event $D_0^{(4)}(t)$ two separate sub-cases should be considered: the first one relates to the situation in that the first (slower) service completes before t, while the second one describes the opposite case. So, we have:

$$\begin{aligned} D_0^{(4)}(t) = (1-\gamma) \int_{x=0}^{t} ae^{-ax} dx D_0^{(3)}(t) = \gamma \overline{V}(t) \sum_{k=1}^{B-1} \frac{(at)^k}{k!} e^{-at}. \\ \times \left[\int_{y=0}^{t-x} \sum_{k=0}^{B-2} \frac{(ay)^k}{k!} e^{-ay} D_{k+1}(t-x-y) dF^{\star}(y) \right. \\ \left. + F^{\star}(t-x) e^{-a(t-x)} \sum_{k=0}^{B-2} \frac{[a(t-x)]^k}{k!} \right], \end{aligned} \tag{9}$$

where two summands on the right side of (9) correspond to the first and second sub-cases, respectively.

Finally, obviously, we have:

$$D_0^{(5)}(t) = e^{-at}. \tag{10}$$

Now let us consider the system that is non-empty at the opening. Conditioning by the first departure moment after the starting of the system (this moment is a renewal moment in the evolution of the considered queueing system due to memoryless property of exponential distribution of interarrival times), we obtain:

$$\begin{aligned} D_n(t) = \sum_{k=0}^{B-n-1} \int_0^t \frac{(ay)^k}{k!} e^{-ay} D_{n+k-1}(t-y) dF(y) \\ + \overline{F}(t) e^{-at} \sum_{k=0}^{B-n-1} \frac{(at)^k}{k!}, \end{aligned} \tag{11}$$

where: $k \in \{1, \ldots, B-1\}$ and $\overline{F}(t) \overset{def}{=} 1 - F(t)$.

Indeed, the first summand on the right side of (11) relates to the case in which the first message leaves the system after completing its service before time t, while the second one to the opposite case.

Introduce now the Laplace transform (LT) of $D_n(t)$ as follows:

$$\widehat{D}_n(s) \overset{def}{=} \int_0^{\infty} e^{-st} D_n(t) dt, \tag{12}$$

where: $s > 0$.

We are interested in writing representations obtained for $D_0(t), \ldots, D_{B-1}(t)$ in terms of their LTs.

Let us note that (compare the right side of (6))

$$\begin{aligned}&\gamma\int_{t=0}^{\infty}e^{-st}dt\int_{x=0}^{t}ae^{-ax}V(x)D_1(t-x)dx\\&=\gamma a\int_{x=0}^{\infty}e^{-(a+s)x}V(x)dx\int_{t=x}^{\infty}e^{-s(t-x)}D_1(t-x)dt=A(s)\widehat{D}_1(s),\end{aligned}\tag{13}$$

where:

$$A(s)\overset{def}{=}\gamma a\int_{0}^{\infty}e^{-(a+s)x}V(x)dx.\tag{14}$$

Next, we have (see the right side of (7)):

$$\begin{aligned}&\gamma\int_{t=0}^{\infty}e^{-st}dt\int_{y=0}^{t}\sum_{k=1}^{B-1}\frac{(ay)^k}{k!}e^{-ay}D_k(t-y)dV(y)\\&=\gamma\sum_{k=1}^{B-1}\int_{y=0}^{\infty}\frac{(ay)^k}{k!}e^{-(a+s)y}dV(y)\times\int_{t=y}^{\infty}e^{-s(t-y)}D_k(t-y)dt\\&=\sum_{k=1}^{B-1}B_k(s)\widehat{D}_k(s),\end{aligned}\tag{15}$$

where:

$$\widehat{B}_k(s)\overset{def}{=}\int_{0}^{\infty}e^{-(a+s)y}\frac{(ay)^k}{k!}dV(y).\tag{16}$$

According to (8), let us define:

$$C(s)\overset{def}{=}\gamma\int_{0}^{\infty}e^{-(a+s)t}\overline{V}(t)\sum_{k=1}^{B-1}\frac{(at)^k}{k!}dt.\tag{17}$$

Changing the order of integration according to the following scheme (compare the right side of (9)):

$$\int_{t=0}^{\infty}\int_{x=0}^{t}\int_{y=0}^{t-x}\rightarrow\int_{x=0}^{\infty}\int_{t=x}^{\infty}\int_{y=0}^{t-x}\rightarrow\int_{x=0}^{\infty}\int_{y=0}^{\infty}\int_{t=x+y}^{\infty},\tag{18}$$

we obtain:

$$\begin{aligned}&(1-\gamma)\int_{x=0}^{\infty}ae^{-(a+s)x}dx\int_{y=0}^{\infty}\sum_{k=1}^{B-2}\frac{(ay)^k}{k!}e^{-(a+s)y}dF^{\star}(y)\\&\times\int_{t=x+y}^{\infty}e^{-s(t-x-y)}D_{k+1}(t-x-y)dt=\sum_{k=0}^{B-2}E_k(s)\widehat{D}_{k+1}(s),\end{aligned}\tag{19}$$

where:

$$E_k(s)\overset{def}{=}\frac{(1-\gamma)a}{a+s}\int_{0}^{\infty}\frac{(ay)^k}{k!}e^{-(a+s)y}dF^{\star}(y).\tag{20}$$

Similarly (see (9)):

$$(1-\gamma)\sum_{k=0}^{B-2}\frac{a^{k+1}}{k!}\int_{x=0}^{\infty}e^{-(a+s)x}dx\times\int_{t=x}^{\infty}e^{-(a+s)(t-x)}(t-x)^{k}F^{\star}(t-x)dt = \sum_{k=0}^{B-2}G_k(s), \tag{21}$$

where:

$$G_k(s)\overset{def}{=}\frac{(1-\gamma)a}{a+s}\int_0^{\infty}\frac{(at)^k}{k!}e^{-(a+s)t}F^{\star}(t)dt. \tag{22}$$

Obviously, the LT of the right side of (10) gives:

$$\frac{1}{a+s}. \tag{23}$$

Referring now to (12)-(23) we can write:

$$\widehat{D}_0(s)=\sum_{k=1}^{B-1}(\delta_{k,1}A(s)+B_k(s)+E_{k-1}(s))\widehat{D}_k(s)+C(s)+\sum_{k=0}^{B-2}G_k(s)+\frac{1}{a+s}. \tag{24}$$

So, defining:

$$\Theta_k(s)\overset{def}{=}\delta_{k,1}A(s)+B_k(s)+E_{k-1}(s), \tag{25}$$

where: $k\in\{1,\ldots,B-1\}$, and:

$$\Phi(s)\overset{def}{=}C(s)+\sum_{k=0}^{B-2}G_k(s)+\frac{1}{a+s}, \tag{26}$$

we obtain:

$$\widehat{D}_0(s)=\sum_{k=1}^{B-1}\Theta_k(s)\widehat{D}_k(s)+\Phi(s). \tag{27}$$

Similarly, taking LTs of both sides of (11) we get:

$$\widehat{D}_n(s)=\sum_{k=0}^{B-n-1}\alpha_k(s)\widehat{D}_{n+k-1}(s)+\beta_n(s), \tag{28}$$

where: $n\in\{1,\ldots,B-1\}$ and:

$$\alpha_k(s)\overset{def}{=}\int_0^{\infty}e^{-(a+s)y}\frac{(ay)^k}{k!}dF(y) \tag{29}$$

and:

$$\beta_n(s)\overset{def}{=}\sum_{k=0}^{B-n-1}\int_0^{\infty}e^{-(a+s)t}\frac{(at)^k}{k!}\overline{F}(t)dt. \tag{30}$$

4. Explicit Solution in Terms of Laplace Transforms

In this section, we give an explicit solution of the linear system of equations (27)-(28), which is written using a certain auxiliary functional sequence. Firstly, we should reformulate (27)-(28).

Let us apply the following substitution:

$$\widehat{H}_n(s) \stackrel{def}{=} \widehat{D}_{B-n}(s) \tag{31}$$

Equations (27)-(28) has now the following forms:

$$\widehat{H}_B(s) = \sum_{k=1}^{B-1} \Theta_{B-k}(s)\widehat{H}_k(s) + \Phi(s) \tag{32}$$

and:

$$\sum_{k=-1}^{n-1} \alpha_{k+1}(s)\widehat{H}_{n-k}(s) - \widehat{H}_n(s) = \varphi_n(s), \tag{33}$$

where: $n \in \{1, \ldots, B-1\}$ and:

$$\varphi_n(s) \stackrel{def}{=} \widehat{H}_1(s)\alpha_n(s) - \beta_{B-n}(s). \tag{34}$$

To obtain the solution of the system (32)–(33) in a compact form, we use an auxiliary algebraic result. The following lemma can be found in (Korolyuk, 1974; see also Kempa, 2016).

Lemma 1.

Assume that $(u_n(s))$ and $(v_n(s))$ are two given functional sequences, where additionally $u_0(s) \neq 0$. Each solution of the system of infinite number equations of the form:

$$\sum_{k=-1}^{n-1} u_{k+1}(s)x_{n-k}(s) - x_n(s) = v_n(s), \tag{35}$$

where: $n \geq 1$, can be expressed as follows:

$$x_n(s) = M(s)R_n(s) + \sum_{k=1}^{n} R_{n-k}(s)v_k(s), \tag{36}$$

where: $n \geq 1$, $M(s)$ is certain function (independent on n) and the functional sequence $(R_k(s))$ is defined as follows:

$$\begin{gathered} R_0(s) = 0, R_1(s) = u_0^{-1}(s), \\ R_{k+1}(s) = R_1(s)\left[R_k(s) - \sum_{i=0}^{k} u_{i+1}(s)R_{k-i}(s)\right] \end{gathered} \tag{37}$$

for $k \geq 1$.

Let us note that in (32)-(33) the role of $u_k(s)$ and $v_k(s)$ play $\alpha_k(s)$ and $\varphi_k(s)$, respectively, and the unknown functional sequence is now $(\widehat{H}_n(s))$. Moreover, because the number of equations in (32)-(33) is finite, one can use the equation (32) as a kind of a boundary condition that will be helpful to express $M(s)$ explicitly.

In consequence, we have:

$$\widehat{H}_n(s) = M(s)R_n(s) + \sum_{k=1}^{n} R_{n-k}(s)\varphi_k(s), \tag{38}$$

where: $n \geq 1$ and:

$$\begin{gathered} R_0(s) = 0, R_1(s) = \alpha_0^{-1}(s), \\ R_{k+1}(s) = R_1(s)\left[R_k(s) - \sum_{i=0}^{k} \alpha_{i+1}(s)R_{k-i}(s)\right]. \end{gathered} \tag{39}$$

Obviously, it is necessary to find the representation for $\widehat{H}_1(s)$ and $M(s)$ occurring in (34) and (38), respectively.

Substituting $n = 1$ into (38) we obtain:

$$\widehat{H}_1(s) = M(s)R_1(s). \tag{40}$$

Next, let us note that, taking $n = B$ in (38) and applying (34) and (40), we get:

$$\widehat{H}_B(s) = M(s)R_B(s) + \sum_{k=1}^{B} [M(s)R_1(s)\alpha_k(s) - \beta_{B-k}(s)]R_{B-k}(s). \tag{41}$$

Simultaneously, from the other side we have from (32), referring to (34) and (38):

$$\begin{gathered} \widehat{H}_B(s) = \sum_{k=1}^{B-1} \Theta_{B-k}(s)[M(s)R_k(s) \\ + \sum_{i=1}^{k} (M(s)R_1(s)\alpha_i(s) - \beta_{B-i}(s))R_{k-i}(s)] + \Phi(s). \end{gathered} \tag{42}$$

Introduce now the following auxiliary notations:

$$\Gamma_k(s) \stackrel{def}{=} R_k(s) + R_1(s)\sum_{i=1}^{k} \alpha_i(s)R_{k-i}(s)M(s) = FAC1^{-1}(s)FAC2(s), \tag{43}$$

and:

$$\Delta_k(s) \stackrel{def}{=} \sum_{i=1}^{k} \beta_{B-i}(s)R_{k-i}(s). \tag{44}$$

Comparing the right sides of representations (41) and (42) we eliminate $M(s)$ in the following form:

$$M(s) = FAC1^{-1}(s)FAC2(s), \tag{45}$$

where:

$$FAC1(s) \stackrel{def}{=} \Gamma_B(s) - \sum_{k=1}^{B-1} \Theta_{B-k}(s)\Gamma_k(s) \tag{46}$$

and:

$$FSC2(s) \stackrel{def}{=} \Delta_B(s) - \sum_{k=1}^{B-1} \Theta_{B-k}(s)\Delta_k(s) + \Phi(s). \tag{47}$$

Now we have (see (38)):

$$\begin{aligned} \widehat{H}_n(s) &= FAC1^{-1}(s)FAC2(s)R_n(s) \\ &+ \sum_{k=1}^{n} [FAC1^{-1}(s)FAC2(s)R_1(s)\alpha_k(s) - \beta_{B-k}(s)]R_{n-k}(s) \\ &= FAC1^{-1}(s)FAC2(s)[R_n(s) + R_1(s)\sum_{k=1}^{n} \alpha_k(s)R_{n-k}(s)] - \sum_{k=1}^{n} \beta_{B-k}(s)R_{n-k}(s). \end{aligned} \tag{48}$$

Returning to functional sequence $\widehat{D}_n(s)$ (see (32)), we can formulate the following theorem.

Theorem 1.

In the queueing model, the representation for the LT of the tail CDF of the time to the first buffer overflow is given by the following formula:

$$\begin{aligned} \widehat{D}_n(s)(t) &= FAC1^{-1}(s)FAC2(s)[R_{B-n}(s) \\ &+ R_1(s)\sum_{k=1}^{B-n} \alpha_k(s)R_{B-n-k}(s)] - \sum_{k=1}^{B-n} \beta_{B-k}(s)R_{B-n-k}(s), \end{aligned} \tag{49}$$

where: $n \in \{0, \ldots, B-1\}$ the and the representations for $FAC1(s)$, $FAC2(s)$, $R_k(s)$, $\alpha_k(s)$ and $\beta_k(s)$ are given in (46), (47), (39), (29) and (30), respectively.

Just from the definition of $\widehat{D}_n(t)$ we get, as a corollary from Theorem 1, the following representation for the mean value of the time to the first buffer overflow conditioned by the initial buffer state n.

Corollary 1.

The mean time $\boldsymbol{E}_n(\delta_1)$ to the first buffer overflow under condition that the accumulation buffer contains exactly n messages initially is given by:

$$\mathbf{E}_n(\delta_1) = \int_0^{\infty} \mathbf{P}\{\delta_1 > t \mid N(0) = n\}dt = \widehat{D}_n(0). \tag{50}$$

5. Next Buffer Overflow Periods

Defining the next times to buffer overflow by δ_k, where $k = 2,3,\ldots$ (we assume here that appropriate time is measured beginning with the completion epoch of the previous buffer overflow), let us note that after finishing each buffer overflow period the number of messages present in the system equals $B-1$ due to the individual service process organization.

Hence, we have the following corollary.

Corollary 2.

The LT of the probability that the time δ_k to the kth buffer overflow (counting from the completion epoch of the $(k-1)$th such period) exceeds t, where $k = 2,3,\ldots$, is given by:

$$\int_0^\infty e^{-st}\mathbf{P}\{\delta_1 > t \mid N(0) = B-1\}dt = \widehat{D}_{B-1}(s), \tag{51}$$

So is the same as the analogous transform given for the time to the first buffer overflow δ_1 on condition $N(0) = B-1$.

Therefore, we obtain

Corollary 3.

The mean value of the time δ_k to the kth buffer overflow period, where $k = 2,3,\ldots$, is given by:

$$\mathbf{E}(\delta_k) = \widehat{D}_{B-1}(0). \tag{52}$$

6. Conclusions and future work

The paper analyzed the theoretical model of a service unit with periodic suspension or service slowdown. The finite buffer queueing model was proposed with two types of vacations to obtain a compromise between energy savings ability and maintaining the highest possible quality of service. The system of integral equations was solved using an algebraic approach in terms of Laplace transforms. The Laplace transform of the time to the first buffer overflow is obtained, and the mean time to the first overflow is given. The main result is then followed by the time to the k-th buffer overflow ($k = 2,3,\ldots$) distribution and the respective mean time to the k-th buffer overflow. With the explicit solution, a numerical study can be conducted after the inversion of the Laplace transform. It can be done using one of the methods that can be found in the literature (see, for example Abate et al., 2000).

References

1. Abate, J., Choudhury, G.L., Whitt, W. (1999). An Introduction to Numerical Transform Inversion and Its Application to Probability Models. In: W. Grassman (Ed.), *Computational Probability* (pp. 257-323). Boston, MA: Springer.
2. Ait Braham, K., Taleb, S., Aissani, A. (2023). Performance Analysis of a Non-markovian Queue with Differentiated Vacations. *SN Computer Science, 4(5)*, p. 512. Retrieved from: https://link.springer.com/10.1007/s42979-023-02057-9.

3. Bostoen, T., Mullender, S., Berbers, Y. (2013). Power-reduction techniques for data-center storage systems. *ACM Computing Surveys, 45(3)*. Retrieved from: https://doi.org/10.1145/2501654.
4. Chunxia, Y., Shunfu, J. (2018). An energy-saving strategy based on multi-server vacation queuing theory in cloud data center. *The Journal of Supercomputing*, *74(12), 6766-6784*. Retrieved from: http://link.springer.com/10.1007/s11227-018-2513-4.
5. Divya, K., Indhira, K. (2024). Performance analysis and ANFIS computing of an unreliable Markovian feedback queueing model under a hybrid vacation policy. *Mathematics and Computers in Simulation, 218*, pp. 403-419. Retrieved from: https://linkinghub.elsevier .com/ retrieve/ pii/S0378475423005104.
6. Gong, H., Li, R., An, J., Bai, Y., Li, K. (2020). Quantitative Modeling and Analytical Calculation of Anelasticity for a Cyber-Physical System. *IEEE Transactions on Systems, Man, and Cybernetics: Systems, 50(11)*, 4746-4761. Retrieved from: https://ieeexplore.ieee.org/ document/8454896/.
7. Harini, R., Indhira, K. (2024). Dynamical modelling and cost optimization of a 5G base station for energy conservation using feedback retrial queue with sleeping strategy. *Telecommunication Systems, 86(4), 661-690*. Retrieved from: https://link.springer.com/10.1007/s11235-024-01155-0.
8. Jin, S., Hao, S., Qie, X., Yue, W. (2019). A virtual machine scheduling strategy with a speed switch and a multi-sleep mode in cloud data centers. *Journal of Systems Science and Systems Engineering, 28(4)*, pp. 567-589.
9. Jin, S., Qie, X., Zhao, W., Yue, W., Takahashi, Y. (2020). A clustered virtual machine allocation strategy based on a sleep-mode with wake-up threshold in a cloud environment. *Annals of Operations Research, Vol. 293(1)*, pp. 193-212.
10. Kempa, W.M., Venkov, G., Pasheva, V., Kovacheva, R. (2010). *The transient analysis of the queue-length distribution in the batch arrival system with N-policy, multiple vacations and setup times.* AIP Conference Proceedings, Sozopol (Bulgaria): AIP Publishing, pp. 235-242. Retrieved from https://pubs.aip.org/aip /acp/article/1293/1/235-242/815464.
11. Kempa, W.M. (2016). Transient workload distribution in the M/G/1 finite-buffer queue with single and multiple vacations. *Annals of Operations Research, 239(2),* pp. 381-400. Retrieved from http://link.springer.com/10.1007/s10479-015-1804-x.
12. Kempa, W.M. (2019). Analytical Model of a Wireless Sensor Network (WSN) Node Operation with a Modified Threshold-Type Energy Saving Mechanism. *Sensors, 19(14), 3114*. Retrieved from: https://www.mdpi.com/1424-8220/19/14/3114.
13. Korolyuk, V.S. (1974). Boundary Problems for a Compound Poisson Process. *Theory of Probability & Its Applications, 19(1)*, pp. 1-13. Retrieved from: http://epubs.siam.org/doi/10.1137/1119001.
14. Mohammad Shapique, A., Sudhesh, R., Dharmaraja, S. (2024). Transient Analysis of a Modified Differentiated Vacation Queueing System for Energy-Saving in WiMAX.

Methodology and Computing in Applied Probability, 26(3), p. 23. Retrieved from: https://link.springer.com/10.1007/s11009-024-10094-x.

15. Qin, B., Jin, S., Zhao, D. (2019). Energy-Efficient Virtual Machine Scheduling Strategy with Semi-Sleep Mode on the Cloud Platform. *International Journal of Innovative Computing, Information and Control, 15(1), 337-350*. Retrieved from: https://doi.org/10.24507/ijicic.15.01.337.
16. Yin, C., Liu, J., Jin, S. (2020). An Energy-Efficient Task Scheduling Mechanism with Switching On/Sleep Mode of Servers in Virtualized Cloud Data Centers. *Mathematical Problems in Engineering.* Retrieved from: https://www.hindawi.com/journals/mpe/2020/4176308/.
17. Yin, C., Liu, J., Jin, S. (2022). A virtualized data center energy-saving mechanism based on switching operating mode of physical servers and reserving virtual machines. Concurrency and Computation: *Practice and Experience, 34(9), e5785*. Retrieved from: https://onlinelibrary.wiley.com/doi/10.1002/cpe.5785.
18. Zhu, D., Melhem, R., Mosse, D. (2004). The effects of energy management on reliability in real-time embedded systems. *Proceedings of IEEE/ACM International Conference on Computer-Aided Design (ICCAD-2004)*, pp. 35-40.

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ON BLUETOOTH STANDARD QUEUEING-BASED MODELING

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Purpose: The article considers the IEEE 802.15 Bluetooth standard. It presents the general concept of transmission and architecture and describes the BLE (Bluetooth Low Energy) communication protocol. Next, it discusses a queueing-based approach to modeling the IEEE 802.15 standard, in which the mathematical framework is a queueing model with bounded capacity and limited access to the service station.
Design/methodology/approach: The study employs a mathematical modeling approach using queueing theory to analyze the transmission mechanism in Bluetooth networks. Including the Bluetooth communication process, which was represented as a queueing network with multiple nodes. Kendall's classification was applied to define the queueing behavior. Different vacation policies (single vacation, multiple vacation, Bernoulli vacation, and working vacation) were integrated to simulate transmission delays and interruptions.
Findings: Different-type Bluetooth modeling issues are studied compared to analytic solutions proposed for queueing systems. The study explores the queueing-based modeling approach for the IEEE 802.15 Bluetooth standard, mainly focusing on its mathematical framework.
Research limitations/implications: The study employs a mathematical modeling approach using queueing theory to analyze the transmission mechanism in Bluetooth networks. The following methodologies were applied.
Practical implications: Guidelines for a project of Bluetooth network design.
Social implications: Service Station Limitations: The master node exclusively initiates communication with slave nodes, influencing the traffic flow and transmission efficiency.
Originality/value: The mathematical framework is a queueing model with bounded capacity and limited access to the service station, a project of Bluetooth.
Keywords: Bluetooth; queue; queueing-based modeling; limited access to service station.
Category of the paper: Research paper.

1. Bluetooth Standard Transmission – General Concept

The IEEE 802.15 network based on the Bluetooth standard defined in (IEEE, 2015) is widely used for wireless communication over shorter distances. The Bluetooth protocol is used to establish a connection, for example, between smartphones, netbooks, and other peripheral devices. The connection uses the unlicensed 2.4 GHz band and the TDM (Time Division Multiplexing) discipline with a time interval of 625 microseconds. The nodes (devices) form a so-called piconet consisting of at most eight nodes, one of which acts as the master node and the rest - as slave nodes. The master node, as the only one, can transmit data packets in odd time frames. Slave nodes can communicate only in even frames and only if the master node has established contact with them in the previous time frame. Transmission from slave nodes is directed exclusively to the master node. Consequently, data packets received by a slave node are directed to it from the master node.

2. Bluetooth Low Energy

Ultra-low power communication mechanisms are essential for future IoT implementations. Bluetooth Low Energy (BLE) can be crucial to such deployments. BLE was initially introduced in June 2010 in the Bluetooth 4.0 base specification (Pattnaik et al., 2022) and has several unique capabilities compared to traditional Bluetooth (AL-Shareeda et al., 2022; Chen et al., 2021). The BLE protocol was developed for low-power, short-range communications between Internet of Things (IoT) sensors and other devices. BLE is significantly more energy efficient than competing protocols such as ZigBee and ANT. Many research centers conduct research related to the energy consumption of these types of systems. In Siekkinen et al. (2012), the energy consumption of BLE was studied by measuring real devices using a power monitor, and models were proposed for the basic energy consumption behavior observed from the measurement results. The results showed that, compared to ZigBee, BLE is very energy efficient in terms of the number of bytes transmitted per joule released. A review article (Al-Shareeda et al., 2023) notes that Bluetooth low Energy (BLE) has become the standard communication standard for Internet of Things (IoT) nodes due to its extremely low power consumption, simple design, sufficient network coverage, and high data transfer rates. The Bluetooth low-energy concept for the Internet of Things (BLE-IoT) was presented in terms of Bluetooth classic, Bluetooth version, applications for BLE-IoT, and new BLE-IoT functions. The paper presents a taxonomy of literature reviews based on parameter adjustment and collision avoidance approaches. Article Alattar, Mohsen (2023) presents the applications of BLE in healthcare, discussing the benefits and challenges of patient monitoring and medical

devices. These devices' power, wireless technologies, applications, and wearability were discussed. The authors note that Bluetooth Low Energy technology works best for personal use.

Bluetooth Low Energy technology is becoming increasingly widely used in many areas yearly. In 2024, there was a significant increase in its use in IoT devices, including a growing dynamic in implementing electronic labels. This improvement enables a unified retail system where IoT devices from different manufacturers can communicate seamlessly and integrate into a single management platform.

3. Bluetooth Standard

Bluetooth is a short-range wireless communication standard that enables a simple, low-power connection between devices without cables. It transfers data between devices at a distance, depending on the version and transmitter power, of up to 100 meters. Bluetooth uses radio waves in the 2.4 GHz ISM (Industrial, Scientific, and Medical) band (Pu, 2006; Amit, Kamaljit, 2014). Bluetooth is designed to operate with minimal power consumption, making it ideal for mobile devices and accessories (e.g., headphones, smartwatches, fitness sensors). It allows direct communication between devices without using a central server or router.

Bluetooth offers several standards and profiles that define how different devices communicate with each other. The following are example profiles:

- **A2DP (Advanced Audio Distribution Profile)**: high-quality audio transmission.
- **HFP (Hands-Free Profile)**: used in hands-free sets.
- **SPP (Serial Port Profile)**: transmits data via the serial port.
- **BLE (Bluetooth Low Energy)**: used in devices that need to operate with minimal energy consumption.

Bluetooth is one of the most popular wireless communication standards, and it is used in millions of devices, from mobile phones to IoT devices, headphones, speakers, smartwatches, and other accessories.

3.1. Bluetooth Architecture

Figure 1 shows that Bluetooth architecture is divided into three essential parts: controller, host, and applications. A controller is a physical device that can transmit and receive radio signals and understand how these signals can be interpreted as packets containing information. A host is typically a software stack that manages how two or more devices communicate with each other and the ability to provide several different services simultaneously over the radio. Applications use the software stack and the controller to enable the use case.

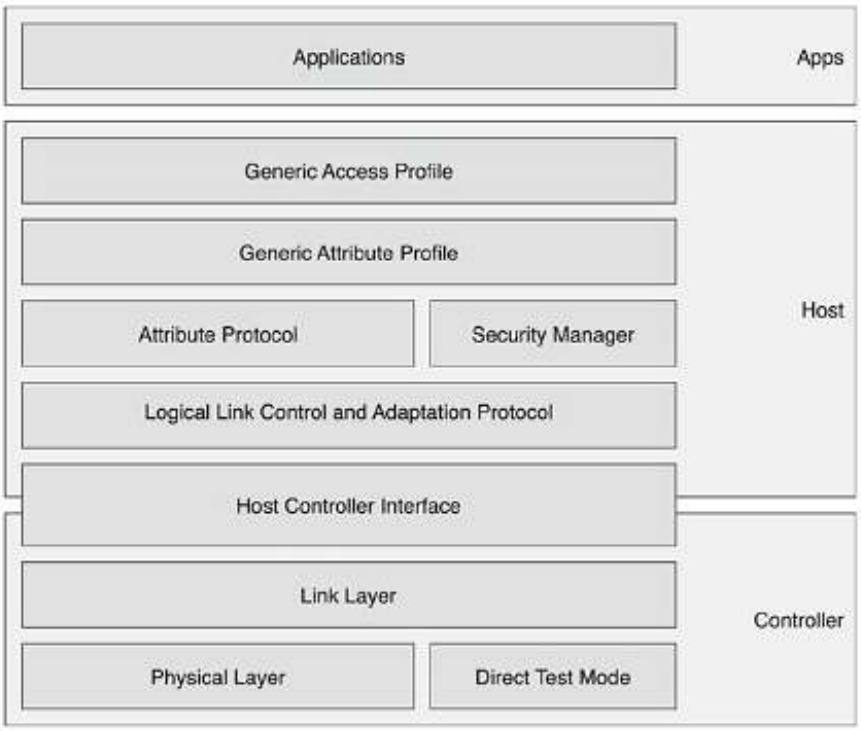

Figure 1. Bluetooth protocol stack.

Source: Heydon, 2012.

A controller is an element consisting of analog and digital parts—radio frequency components and equipment that handle the transmission and reception of packets. The controller communicates with the outside world through the antenna and with the host through the host controller interface.

The host contains multiplexing layers, protocols, and procedures to perform assigned tasks. The host is built on the upper host controller interface. In addition, it includes a protocol for the control and adaptation of logical links and a multiplexing layer. It also contains two essential system components: the Security Manager, responsible for authenticating and configuring secure connections, and the Attribute Protocol, which provides data about the device's state. The general access profile defines how devices find and connect interoperable.

Above the controller and the host, there is the application layer. The application layer defines three types of specifications: characteristics, service, and profile. Each of these specifications is based on an overall attribute profile. A generic attribute profile defines a grouping of features and service attributes, and applications define specifications that use these attribute groups.

3.2. Types of Division of the Bluetooth Protocol Stack

The Bluetooth specification defines one division of the protocol stack between the controller and the host, but many other divisions can be used to enable a low-power product.

3.2.1. Single-Chip Division

The solution is to build a platform for prototyping or a cheap product for a short production series. An integrated circuit that includes all the stack elements and a small, non-volatile memory chip. When the power is turned on, the contents of nonvolatile memory are read into a single chip and executed.

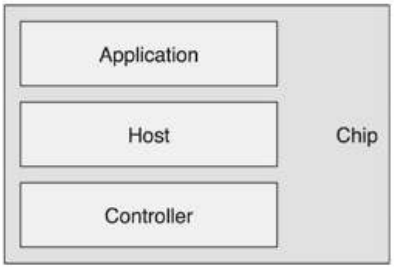

Figure 2. Single-chip division.

Source: Heydon, 2012.

3.2.2. Two-Chip Division

Mobile phones and computers already have very efficient processors that enable them to run the entire host software stack and applications. Therefore, a two-chip solution is used. In the solution, the controller is on one chip, and the host and applications are on a second separate chip. This architecture division works perfectly in devices equipped with a powerful processor but is not ideal for any other type of device.

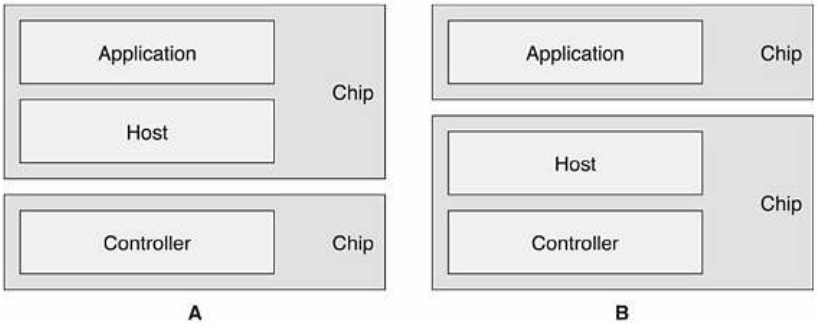

Figure 3. Two-chip division.

Source: Heydon, 2012.

One chip may contain the controller and host in a two-chip solution, while the other houses the applications. Thanks to this solution, the application chip can be a tiny microprocessor with low power consumption.

3.2.3. Multi-Chip Division

It is also possible to create multi-chip solutions. For example, a standard controller, host chip, and application chip could be combined into one chip. The host chip would require many separate interfaces.

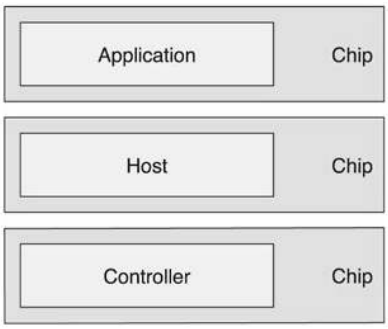

Figure 4. Multi-chip division.
Source: Heydon, 2012.

4. New Features of Bluetooth Low Energy

Many new features and improvements have been introduced in BLE that increase speed, enable support for IoT devices, increase range, and increase battery life. Below is a description of some of them: As of BLE 5.1, General Attribute Profile (GATT) caching is available, which reduces the time it takes to learn the GATT database when previously connected devices are reconnected. A slot availability mask has been introduced so BLE can exist near long-term transmission (LTE) and avoid packet loss, remaining on its channel and not interfering with other nearby LTE transmissions. The latest versions of BLE offer improved Security Manager (SM) technology. The SM function in Bluetooth operates at the connection protocol level. It ensures that only authorized devices can exchange information, and that data transmitted via Bluetooth remains protected against eavesdropping and unauthorized access. Increased the maximum message size for BLE v5.x to 255 bytes compared to 31 in BLE v4. A channel selection algorithm that allows for a significant increase in data transmission throughput has been introduced. In Bluetooth Low Energy (LE) technology, channel selection ensures data transmission efficiency and minimizes interference. Channel selection occurs as part of the connection process and during data transmission. Bluetooth LE uses 40 channels in the 2.4 GHz band: 37 data channels - channels 2-37, channels 37, 38, and 39 are reserved for the so-called advertising, i.e., announcing the availability of a device (advertising channels). All channels are distributed in the range of 2402 MHz to 2480 MHz, with a spacing of 2 MHz between each channel. Channels 37, 38, and 39 are particularly important because they are used to discover and connect devices. When a Bluetooth LE device begins to broadcast its availability, it selects one of three advertising channels (37, 38, 39). The channel is selected randomly to avoid interference from other Bluetooth devices. When transmitting data, Bluetooth LE uses frequency hopping, which means that devices change the frequency on different channels during transmission to minimize the impact of interference. The device selects channels based

on SNR (Signal-to-Noise Ratio) if the connection has already been established. The channel with the better SNR is selected for communication, which means the system avoids channels with high interference, e.g., from other devices operating in the same band. BLE v5.2 introduced the dual audio connectivity function, thanks to which a mobile device can connect to two audio devices simultaneously. The range has been increased - BLE v5 is 200 meters outdoors and 40-50 meters indoors, so it can be used as an alternative to wireless Internet via Wi-Fi. Reduced battery consumption - BLE v5 power consumption is almost halved compared to previous versions thanks to signal modulation design and spectrum utilization improvements. Compared to BLE v5, which can reach up to 2Mbps, BLE v4 can only reach speeds up to 1Mbps. Data transfer speeds between the wearable device and the mobile application can be increased, and live streaming is possible with BLE v5. Devices can be reprogrammed to improve speed or expand the scope of their operations.

5. Queueing-Based Approach to IEEE 802.15 Standard

5.1. Outside Observer Point of View

From the point of view of the potential mathematical model of the transmission based on the 802.15 (Bluetooth) standard, we are dealing with independent sources (nodes) generating messages with different intensities (rates). If the piconet contains nodes (including the master node), independent Poisson processes can describe the input traffic to the nodes with (generally) different intensities $\lambda_1, \ldots, \lambda_r$. This approach has the following theoretical justification. As is known, the Palm-Khintchine theorem (see, e.g. Heyman, Sobel, 2003) implies that a Poisson process can reasonably approximate the superposition of many independent event streams (of any type). In the case of the master node, the input traffic directed to this node comes from independently transmitting slave nodes. On the other hand, each of the slave nodes also "receives" a stream of "mixed" messages (originally coming from different slave nodes and the master node) directed to this node by the master node.

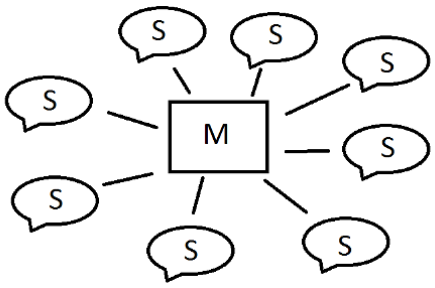

Figure 5. An example of a piconet with master and slave nodes.

Source: https://www.entcengg.com/bluetooth-architecture-layers-bluetooth/, 2024.11.27.

Of course, the message processing time is closely related to the network node and its technical specifications. All nodes are equipped with small (typically) buffers accumulating incoming messages. From the point of view of an external observer, a piconet can therefore be modeled by a queueing network consisting of r independent nodes, each of which (including the master node) can be described in Kendall's classification of queueing systems (see Kendall, 1953) as an $M/G/1/B$ model, in which an additional restriction on access to service stations is applied.

5.2. Network Node Point of View

Applying the classic 802.15 communication standard from the point of view of a single network node (sender-receiver) is associated with the need to comply with the rules for sending messages in specific time windows. As described above, the input process of messages (directed to a given node by the network's parent node) can be well modeled using the Poisson process. However, when sending our messages, we are dealing with cyclically repeating periods of sending and abstention from sending. We can, therefore, say that a given node (which is not the network's master node) cyclically passes within the 802.15 protocol from the listening phase to the phase of simultaneous listening and sending.

As a mathematical model of the above process (for a single "normal" network node), we can, therefore, propose a queueing model with a Poisson input stream of messages and a finite possible queue length (due to the finite capacity of the actual accumulating buffer of a mobile device using the Bluetooth protocol). In such a proposed model, the service station (understood here as a channel (band) used in communication with the master node) would be periodically switched off, corresponding to periods of transmission suspension in the outside direction.

5.3. Queueing Models with Limited Access to Service Channel

The literature on queueing models with periodic service suspensions is growing extensively. Single and multiple vacation policies (SV or MV, respectively) are the classic ones. In the former case, the service station becomes unavailable for the messages for a single, usually random, period (single vacation). After finishing the vacation, the process usually restarts. However, the vacation period can be preceded by closing time and finished by setting up time during which the service station becomes completely prepared to start processing. The special case of the single vacation policy is T-policy (see, e.g. Heyman, 1977; Levy, Yechiali, 1976), in which, once the busy period is over and the system is cleared of messages, the service station becomes unavailable for a fixed period T. In the multiple vacation policy, the server takes successive vacations until, at the completion moment of one of them, at least one message waiting for service is detected. Analytic results for transient stochastic characteristics in queueing models with SV and MV policies can be found, e.g., in (Kempa, 2011, 2012, 2014, 2016, 2019; Kempa, Marjasz, 2020).

Later, a modification of the classic scheme was proposed so that the server could continuously take a maximum of a predefined number of vacations. This policy is called multiple adaptive vacation (MAV). The case of a batch arrival process and the balking behavior of customers in the MAV-type model are considered in (Ke, Chu, 2006) and (Ke, 2007), respectively. In (Zhang, Tian, 2001), a discrete-time queueing model governed by the MAV policy is investigated. Some more complex queueing models with MAV mechanisms can also be found, e.g., in Ke et al. (2010) and Ke, Chang (2009), where the threshold scheme (N-policy) and feedback customer behavior are studied, respectively. It seems that the two proposals mentioned above can be implemented in queueing models of transmission based on the Bluetooth standard. The transmission is restarted in the N-policy if at least N waiting messages are accumulated in the buffer. In the case of the feedback mechanism, after the service is completed, the customer can return to the queue and go through the service process again. This solution can be used when the transmission is error-prone or disrupted. As a result, it becomes necessary to send the message again.

In the Bernoulli scheduled vacation (see, e.g. Choudhury, 2008; Gupta, Skidar, 2006; Tadj et al., 2006), the service station may go into sleep mode (during which the service process is suspended) or not with a predetermined probability. This type of mechanism or its modification can be used in the case of a Piconet network operating according to the Bluetooth standard, which sometimes leaves (disconnects) and then returns to it.

In Servi, Finn (2002), the working vacation (WV) mechanism in a single-server model was proposed. In the WV policy, the service station offers them at a reduced speed instead of completely suspending message processing. The WV mechanism can model transmission using the Bluetooth protocol with variable channel bandwidth (message transfer rate). The waiting time distribution in the Markov queueing model with WV is studied in Liu et al. (2007). The case of the group-arrival system is analyzed in Xu et al. (2009). A general independent input stream model and multiple working vacations can be found in Baba (2005) and Banik et al. (2007), where an infinite and finite accumulation buffer is assumed, respectively. Transient results can be found for WV-type models with finite capacities in Kempa, Kobielnik (2018) and Kobielnik, Kempa (2021).

Since the famous work Leland et al. (1994), which described the self-similar nature of packet traffic in the Ethernet network, a significant number of works have been published in which the message input process described utilizing the MAP or BMAP process (in the case of batch arrivals) is used, in which the phenomenon of stream autocorrelation occurs (see, e.g. Wu et al., 2009; Gupta, Skidar, 2006). These solutions can also be applied to the transmission modeling using the Bluetooth standard, which is also related to the packet network.

References

1. Alattar, A.E., Mohsen, S. (2023). A survey on smart wearable devices for healthcare applications. *Wireless Personal Communications, 132*, pp. 775-783.
2. Al-Shareeda, M.A. et al. (2022). Provably secure with efficient data sharing scheme for fifth-generation (5G)-enabled vehicular networks without road-side unit (RSU). *Sustainability, 14(16), 9961*.
3. Al-Shareeda, M.A., Murtaja, A., Selvakumar, M., Karuppayah, S. (2023). Bluetooth low energy for internet of things: review, challenges, and open issues. *Indonesian Journal of Electrical Engineering and Computer Science, 31*, pp. 1182-1189.
4. Amit, J., Kamaljit, I.L. (2014). A comparative study of lossless compression algorithm on text data. *International Journal of Electronics and Information Engineering, 1(1)*, pp. 45-52.
5. Baba, Y. (2005). Analysis of a GI/M/1 queue with multiple working vacations. *Operations Research Letters, 33*, pp. 201-209.
6. Banik, A.D., Gupta, U.C., Pathak, S. (2007). On the GI/M/1/N queue with multiple working vacations - analytic analysis and computation. *Applied Mathematical Modelling, 31*, pp. 1701-1710.
7. Chen, D. et al. (2021). Coexistence and interference mitigation for WPANs and WLANs From traditional approaches to deep learning: a review. *IEEE Sensors Journal, 22(22)*, 25561-25589.
8. Choudhury, G. (2008). Steady state analysis of an M/G/1 queue with linear retrial policy and two phase service under Bernoulli vacation schedule. *Applied Mathematical Modelling 32(11)*, 2480-2489.
9. Choudhury, G., Madan, K.C. (2004). A two phase batch arrival queueing system with a vacation time under Bernoulli schedule. *Applied Mathematics and Computation, 149*, pp. 337-349.
10. EntcEngg Team (2004). *Bluetooth Architecture and Layers of Bluetooth*. Retrieved from: https://www.entcengg.com/bluetooth-architecture-layers-bluetooth/, 27.11.2024.
11. Gupta, U.C. Sikdar, K. (2006). Computing queue length distributions in MAP/G/1/N queue under single and multiple vacation. *Applied Mathematics and Computation, 174(2),* pp. 1498-1525.
12. Heydon, R. (2012). *Bluetooth Low Energy: The Developer's Handbook*. New York: Prentice Hall.
13. Heyman, D.P. (1977). T-policy for the M/G/1 queue. *Management Science, Vol. 23, No. 7,* pp. 775-778.

14. Heyman, D.P., Sobel, M.J. (2003). Superposition of renewal processes. In: Stochastic *Models in Operations Research: Stochastic Processes and Operating Characteristics*. Mineola, New York: Dover Publications, Inc.
15. IEEE (2015). *IEEE 802.15 Working Group for Wireless Specialty Networks (WSN)*. Retrieved from: http://grouper.ieee.org/groups/802/15, 27.11.2024.
16. Ke, J.C. (2007). Operating characteristic analysis on the M[x]/G/1 system with a variant vacation policy and balking. *Applied Mathematical Modelling, 31*, pp. 1321-1337.
17. Ke, J.C., Chang, F.M. (2009). Modified vacation policy for M/G/1 retrial queue with balking and feedback. *Computers & Industrial Engineering, 57*, pp. 433-443.
18. Ke, J.C., Chu, Y.K. (2006). A modified vacation model M[x]/G/1 system. *Applied Stochastic Models in Business and Industry, 22*, pp. 1-16.
19. Ke, J.C., Huang, H.I., Chu, Y.K. (2010). Batch arrival queue with N-policy and at most J vacations. *Applied Mathematical Modelling, 34*, pp. 451-466.
20. Kempa W.M. (2011). Analysis of departure process in batch arrival queue with multiple vacations and exhaustive service. *Communications in Statistics - Theory and Methods 40(16)*, pp. 2856-2865.
21. Kempa, W.M. (2012). The virtual waiting time in a finite-buffer queue with a single vacation policy. Analytical and Stochastic Modeling Techniques and Applications, 19th International Conference, ASMTA 2012, Grenoble, France, June 4-6, Proceedings. Springer, pp. 47-60.
22. Kempa, W.M. (2014). On transient queue-size distribution in the batch-arrivals system with a single vacation policy. *Kybernetika, 50(1)*, pp. 126-141.
23. Kempa, W.M. (2016). Transient workload distribution in the M/G/1 finite-buffer queue with single and multiple vacations. *Annals of Operations Research, 239(2)*, pp. 381-400.
24. Kempa, W.M. (2019). Analytical model of a wireless sensor network (WSN) node operation with a modified threshold-type energy saving mechanism. *Sensors, 19(14)*.
25. Kempa, W.M., Kobielnik, M. (2018). Transient solution for the queue-size distribution in a finite-buffer model with general independent input stream and single working vacation policy. *Applied Mathematical Modelling, 59*, pp. 614-628.
26. Kempa, W.M., Marjasz, R. (2020). Distribution of the time to buffer overflow in the M/G/1/N-type queueing model with batch arrivals and multiple vacation policy. *Journal of the Operational Research Society, 71(3)*, pp. 447-455.
27. Kendall, D.G. (1953). Stochastic processes occurring in the theory of queues and their analysis by the method of the imbedded Markov chain. *The Annals of Mathematical Statistics, 24(3)*, pp. 338-354.
28. Kobielnik, M., Kempa, W.M. (2021). On the time to buffer overflow in a queueing model with a general independent input stream and power-saving mechanism based on working vacations. *Sensors, 21(16)*.

29. Leland, W.E., Taqqu, M.S., Willinger, W., Wilson, D.V. (1994). On the self-similar nature of Ethernet traffic (extended version). *IEEE/ACM Transactions on Networking, 2(1)*, pp. 1-15.
30. Levy, Y., Yechiali, U. (1976). Utilization of idle time in an M/G/1 queueing system. *Management Science, 22,* pp. 202-211.
31. Liu, W.Y., Xu, X.L., Tian, N. (2007). Stochastic decompositions in the M/M/1 queue with working vacations. *Operations Research Letters, 35*, pp. 595-600.
32. Pattnaik S.K. et al. (2022). Future wireless communication technology towards 6G IoT: an application-based analysis of IoT in real-time location monitoring of employees inside underground mines by using BLE. *Sensors, 22(9)*, *No. 3438*.
33. Pu, I.M. (2006). *Fundamental Data Compression*. Amsterdam: Elsevier.
34. Servi, L.D., Finn, S.G. (2002). M/M/1 queues with working vacations (M/M/1/WV). *Performance Evaluation, 50*, pp. 41-52.
35. Siekkinen, M., Hiienkari, M., Nurminen, J., Nieminen, J. (2012). How low energy is Bluetooth low energy? Comparative measurements with ZigBee/802.15.4. *IEEE Wireless Communications and Networking Conference Workshops (WCNCW)*. Paris, France.
36. Tadj, L., Choudhury, G., Tadj, C. (2006). A quorum queueing system with a random setup time under N-policy and with Bernoulli vacation schedule. *Quality Technology & Quantitative Management, 3(2)*, pp. 145-160.
37. Wu, J., Liu, Z., Peng, Y. (2009). On the BMAP/G/1 G-queues with second optional service and multiple vacations. *Applied Mathematical Modelling, 33*, pp. 4314-4325.
38. Xu, X.L., Liu, M.X., Zhao, X.H. (2009). The balk input M[x]/M/1 queue with working vacations. *Journal of Systems Science and Systems Engineering, 18(3)*, pp. 358-368.
39. Zhang, Z.G., Tian, N. (2001). Geo/G/1 queue with multiple adaptive vacations. *Queueing Systems, 38(4)*, pp. 419-429.

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FROM BOLTZMANN EQUATION TO NAVIER-STOKES

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Purpose: The objective of this article is to present a detailed derivation of the N-S system of equations from the more general Boltzmann equation.
Design/methodology/approach: This paper presents a derivation of general conservation equations based on the Boltzmann equation. It collates essential information from statistical mechanics and mathematical analysis. As previously stated, the objective is to collate all the requisite derivations of the NS equations from the Boltzmann equation to provide a comprehensive foundation for further study and to address frequently omitted steps. Such derivations can be found in existing literature, but they are often less detailed or are scattered across extensive studies where a single subsection is devoted to them. Conversely, a comprehensive grasp of the interconnections between the two equations facilitates a profound comprehension of the fundamental tenets of LBM. Furthermore, it illuminates the methodology for employing the solution of the Boltzmann equation to simulate fluid dynamics, a technique that can prove invaluable in the development of novel LBM applications.
Findings: A comprehensive set of assumptions and derivations which is often absent from the literature on this topic.
Originality/value: The manner in which the material is presented is original or challenging to locate, according to the authors' knowledge.
Keywords: mathematics, statistical mechanics, computational fluid mechanics.
Category of the paper: Mathematical Physics, Theoretical Fluid Dynamics.

1. Introduction

The Navier-Stokes (N-S) equations are equations that mathematically express the balance of momentum and conservation of mass for moving Newtonian fluid. Sometimes the N-S equations are accompanied by equations of state relating to pressure, temperature, and density.

In essence, the N-S equations are a set of partial differential equations that describe the changes in velocity, pressure, and density at any point in a fluid depending on the forces (gravity, viscosity, external forces) acting on the fluid at that point.

The N-S equations include in case of compressible and viscid flow:

- The equation of continuity (describing the principle of conservation of mass):

$$\frac{\partial \rho}{\partial t} + \nabla \circ (\rho \vec{u}) = 0 \tag{1}$$

  which states that the mass of the system must remain constant over time.

- Momentum equations (a set of equations describing the principle of conservation of momentum in j-th geometric direction):

$$\frac{\partial (\rho\, u_j)}{\partial t} + \nabla \circ \left(\rho\, \vec{u} u_j + \vec{P_j} - \vec{\pi_j}\right) - F_j = 0 \tag{2}$$

  expressing the fact that the rate of change of momentum the of the fluid element is caused only by the mass forces F_j and stresses $\vec{P_j} - \vec{\pi_j}$.

- Internal energy equation:

$$\frac{\partial E}{\partial t} + \vec{u} \circ \nabla E = -P \nabla \circ \vec{u} + \Psi - \nabla \circ \vec{\Phi} \tag{3}$$

  denoting that in any process change in internal energy is caused by pressure, viscous dissipation and changes of heat conduction flux.

The Navier-Stokes equations are still difficult to solve analytically, especially for complex geometries and boundary conditions, so they are usually solved numerically using computational fluid dynamics (CFD) techniques. For some time, another approach to solving the equations of conservation of mass, momentum and energy involving the use of the so-called Lattice Boltzmann Method has been gaining popularity.

The Lattice Boltzmann Method (LBM) is a method derived from the Boltzmann density equation, introduced by Hardy et al. in 1973 as a simplified approach to solving fluid dynamics problems (Cf. Hardy, 1973a, 1973b). Compared to traditional methods for solving Navier-Stokes equations, the LBM method has several advantages, including simplicity, efficiency, and the ability to handle complex geometries and boundary conditions.

Like any other method, LBM is not fully universal, and some difficulties are encountered when using it. A significant complication is problems requiring the construction of adaptive lattices and defining boundary conditions on the edges of areas with curved geometry and geometry not matched to a discrete lattice. The still unsolved problem is the use of LBM to model flows with large heat gradients and fully compressible flow. Modeling of thermoacoustic effects is still a matter of active research. Various proposals for solving these difficulties can be found in the literature (Zhao, 2020; Basu, 2020; Li, 2016), which does not change the fact that the development of LBM for various applications is a current and interesting research problem.

It should be noted that the Boltzmann equation and the Navier-Stokes equations describe different aspects of fluid dynamics and are not directly comparable in generality. The Boltzmann equation is a more fundamental description of the flow because it considers the behavior of individual fluid molecules and their collisions. It is a statistical equation that describes the change in the probability distribution of molecules with a fixed velocity in a fixed area.

The Navier-Stokes equations, on the other hand, are used to describe the continuum of fluid dynamics. They describe the macroscopic behavior of a fluid, such as its velocity, pressure, and density, and are more suitable for describing fluid flow at larger scales. One needs to reduce the amount of information coming from the Boltzmann equation to obtain the solution of Navier-Stokes equations. This is done by computing moments of the Boltzmann equation and will be covered in this work.

According to the idea, the Lattice Boltzmann Method does not numerically solve the equations of conservation of macroscopic properties such as mass, momentum, and energy (as it is in CFD), but models a fluid consisting of fictitious mesoscopic populations that move along a discrete grid called a lattice. The distribution of the populations in the grid is described by a set of discrete probability distribution functions that evolve over time according to a simplified version of the Boltzmann equation. In LBM, the Navier-Stokes equations are therefore not solved directly. However, their solutions are reconstructed from the solution of the Boltzmann equation. This apparent complication makes it possible to create a flow modeling procedure that is surprisingly simple to implement. This approach is possible since, under certain assumptions, the N-S equations can be derived from the more general Boltzmann equation.

In the literature, one can often find the statement that the Boltzmann equation is a more general equation than the N-S equation. On the other hand, it is difficult to find a detailed derivation of the relationship between these equations. This paper undertakes to show step-by-step how to derive from the Boltzmann equation all three equations representing the conservation law of mass, momentum, and energy.

It may be noted that much of the literature encountered leads ultimately to a series of articles written in the late 1940s by Harold Grad. These deal with the theoretical derivation of the N-S equations from the Boltzmann equation (Grad, 1949a) and also give a number of useful properties of Hermite polynomials, which are used in the discretization of the Boltzmann equation (Grad, 1949b). The paper also uses some of the designations and transitions from (Shu, 1991). Historically, Boltzmann's lattice method was first derived more experimentally from so-called lattice gas automata. More recent overview of applications can be found in (Li, 2020). An overview of the development of this theory up to 2000 with early examples of calculations can be found in (Li-Shi, 2000). Nowadays, methods based on LBM allow calculations of, for example, flows related to combustion and thermoacoustic phenomena (Miled, 2020; Bhairapurada, 2022; Taileb, 2022) it can also be applied to microfluidic phenomena (cf. Xu, 2021).

In most works dealing with LBM, it is emphasized that the LBM method uses the fact that instead of solving the N-S equations, the Boltzmann equation is solved, which, although more general, is better suited for discretization. The very derivation of the relationships between the Boltzmann and N-S equations is often incomplete or omitted in literature. Meanwhile, a full understanding of the relationship between the two descriptions helps to thoroughly understand the essence of LBM and indicate how to use the solution of the Boltzmann equation to model flow phenomena, including those caused by thermal phenomena.

This article aims to present a very detailed derivation of the equations of continuity, N-S equations, and the energy equation from the more general Boltzmann equation. We believe that the description using the language of mathematics helps in the development of methods for describing physical phenomena and the development of simulation methods.

2. Boltzmann equation

The Boltzmann equation is a partial differential equation that describes the behavior of a gas at the molecular level. It describes how the distribution of molecules changes over time because of collisions between them. The basic concept used here is the distribution function f that describes the distribution of molecules in phase space. This function tells the number of molecules (in other formulations mass of molecules) at a given point of 7-dimensional phase space – three spatial coordinates, three velocity components and temporal coordinate. It is worth noting that $\mathrm{f} = \mathrm{f}(\vec{x}, \vec{v}, \mathrm{t})$.

The change occurring with respect to time in the value of the function f is described by the total derivative[1]: $\frac{df}{dt}$. Since the redistribution of molecules occurs only because of their collision, it can be written that:

$$\frac{df}{dt} = \Omega(f) \tag{4}$$

Where the occurring on the right-hand side of the source term Ω is the so-called *collision operator*. The original form of the collision operator given by Boltzmann is expressed by an integral that considers different collision angles. Due to its complex form, the operator in this form is not suitable for simulations, so the standard approach is to use approximations of it with much simpler operators. The typical approach is to use the BGK collision operator. In this formulation, the distribution function tends exponentially to the equilibrium distribution function.

[1] In engineering science, the total derivative is often called the substantial derivative and uses the symbol $\frac{Df}{Dt}$.

From the physical interpretation of derivatives:

$$v_i = \frac{dx_i}{dt},\ a_i = \frac{dv_i}{dt}$$

it follows that the equation (4) describing changes in the distribution function takes the form:

$$\frac{\partial f}{\partial t} + \sum_{i=1}^{3}\left(v_i \frac{\partial f}{\partial x_i} + \frac{F_i}{\rho}\frac{\partial f}{\partial v_i}\right) = \Omega(f). \tag{5}$$

This equation is called the Boltzmann equation.

In the equation (5), according to Newton's second law of dynamics $a_i = F_i/m$, the acceleration is written in terms of the external force $\vec{F} = (F_1, F_2, F_3)$, where F_i denotes the force in the i-th direction per unit volume. The variable ξ_i means velocity in the appropriate direction in the velocity space[2].

Solving the Boltzmann equation in the general case is a difficult task due to the complexity of the collision operator, especially for systems with many molecules. For this reason, practical applications usually use an approximation of the Ω operator by the so-called BGK collision operator (proposed by Bhatnagar, Gross and Krook in (Bhatnagar, 1954)) of the form

$$\Omega(f) = -\frac{1}{\tau}(f - f^{eq}), \tag{6}$$

where τ denotes the relaxation time, and f^{eq} is the so-called equilibrium solution.

The equation (5) with the collision operator taken in this way is called the simplified Boltzmann equation.

The function f^{eq} is an equilibrium distribution function representing the steady state of the system in which the fluid is in equilibrium. This interpretation means that f^{eq} takes the form of the Maxwell-Boltzmann distribution, which is expressed in the three-dimensional case by the following formula:

$$f^{eq}(\vec{x}, \vec{v}, t) = \left(\frac{m}{2\pi k_B T}\right)^{\frac{3}{2}} \exp\left(-m\,\frac{|\vec{v} - \vec{u}|^2}{2k_B T}\right), \tag{7}$$

where:

m - denotes mass of molecule,

k_B - Boltzmann constant,

T - temperature,

$\vec{v}$ - intrinsic molecule velocity,

$\vec{u}$ - macroscopic fluid velocity (hence $\vec{w} = \vec{v} - \vec{u}$ is the velocity fluctuation of the molecule).

[2] Since the considerations are carried out with respect to a unit volume, the mass m can be replaced by the density of the fluid ρ.

3. From Boltzmann equation to conservation laws

The fact that the Boltzmann equation is more general than the N-S equations means that its solution (in selected cases) is the solution of the equations of fluid dynamics (a system including the equations (1), (2), (3)).

From the form of the collision operator, it follows that f tends exponentially to the Maxwell-Boltzmann distribution f^{eq} and locally conserves mass, momentum and energy. Note also that it follows from the definition of the function f that[3]:

$$\rho(\vec{x},t) = \int_{\mathcal{V}} m \cdot f(\vec{x},\vec{v},t)\, d^3v, \tag{8}$$

where:

m - the mass of the molecule,

$\mathcal{V}$ - the set of all velocities in all possible directions.

3.1. From Boltzmann to continuity equation

The continuity equation (1) is a relation derived from the principle of conservation of mass. Multiply Boltzmann's equation (5) by the mass of the molecule m and integrate over all possible velocities (i.e., over d^3v). We get:

$$\underbrace{\int_{\mathcal{V}} m \cdot \frac{\partial f}{\partial t}\, d^3v}_{(\mathrm{B1}_1)} + \underbrace{\int_{\mathcal{V}} m \cdot \sum_{i=1}^{3} v_i \frac{\partial f}{\partial x_i}\, d^3v}_{(\mathrm{B1}_2)} + \underbrace{\int_{\mathcal{V}} m \cdot \sum_{i=1}^{3} \frac{F_i}{\rho} \frac{\partial f}{\partial v_i}\, d^3v}_{(\mathrm{B1}_3)} = \underbrace{0}_{\mathrm{B1}_4}.$$

where:

$(\mathrm{B1}_1)$

$$\int_{\mathcal{V}} m \cdot \frac{\partial f}{\partial t}\, d^3v = \frac{\partial}{\partial t} \underbrace{\int_{\mathcal{V}} m \cdot f\, d^3v}_{\rho(\vec{x},t)} = \frac{\partial \rho}{\partial t}$$

$(\mathrm{B1}_2)$ note that[4]:

$$\int_{\mathcal{V}} m \cdot v_i \frac{\partial f}{\partial x_i}\, d^3v = \frac{\partial}{\partial x_i} \underbrace{\int_{\mathcal{V}} v_i \cdot mf\, d^3v}_{u_i \rho(\vec{x},t)} = \frac{\partial (u_i \rho)}{\partial x_i}$$

Thus:

$$\int_{\mathcal{V}} m \cdot \sum_{i=1}^{3} v_i \frac{\partial f}{\partial x_i}\, d^3v = \sum_{i=1}^{3} \int_{\mathcal{V}} m \cdot v_i \frac{\partial f}{\partial x_i}\, d^3v = \frac{\partial (u_1\rho)}{\partial x_1} + \frac{\partial (u_2\rho)}{\partial x_2} + \frac{\partial (u_3\rho)}{\partial x_3}$$

$$= \left[\frac{\partial}{\partial x_1}, \frac{\partial}{\partial x_2}, \frac{\partial}{\partial x_3}\right] \circ [\rho u_1, \rho u_2, \rho u_3] = \nabla \circ (\rho \vec{u})$$

---

[3] To simplify the notation, it was assumed that the integral in (8) means $\iiint_{\mathcal{V}} m \cdot f(\vec{x},\vec{v},t)\, dv_1\, dv_2\, dv_3$

[4] v_i is the component of the molecule's own velocity, and u_i is the component of the molecules' average velocity (macroscopic velocity) in the fluid region.

(B1$_3$) because of:

$$\int_v m \cdot \frac{\partial f}{\partial v_i}\frac{F_i}{\rho}\, d^3v = \frac{\partial}{\partial v_i}\frac{F_i}{\rho}\underbrace{\int_v m \cdot f\, d^3v}_{\rho(\vec{x},t)} = \frac{\partial F_i}{\partial v_i} = 0,$$

we obtain:

$$\sum_{i=1}^{3}\int_v m \cdot \frac{\partial f}{\partial v_i}\frac{F_i}{\rho}\, d^3v = m\sum_{i=1}^{3}\frac{\partial F_i}{\partial v_i} = 0$$

The zeroing of the derivative of the external force after the velocities is because the force does not depend on the velocity of the molecules in the fluid.

(B1$_4$) According to the principle of conservation of mass, the right-hand side of the equation disappears, since molecules neither appear nor disappear because of collisions.

In view of the above, it is easy to see how the continuity equation (5) follows from the Boltzmann equation (1):

$$\begin{array}{ccccccc} \dfrac{\partial f}{\partial t} & + & \displaystyle\sum_{i=1}^{3} v_i \frac{\partial f}{\partial x_i} & + & \displaystyle\sum_{i=1}^{3} \frac{F_i}{\rho}\frac{\partial f}{\partial v_i} & = & \Omega(f) \\ \Downarrow & & \Downarrow & & \Downarrow & & \Downarrow \\ \dfrac{\partial \rho}{\partial t} & + & \nabla \circ (\rho \vec{u}) & + & 0 & = & 0 \end{array}$$

3.2. From Boltzmann to momentum equations

Momentum equations are derived from the principle of conservation of momentum. Let us consider a certain quantity connected with a molecule, such as mass m or momentum in a certain direction mv_i. For short let us denote such quantity with C.Then, the integral

$$\int_v C\, f\, d^3v = \langle C \rangle$$

denotes the value of C averaged with respect to velocity. Assume, for the purposes of the calculations in this subsection, that we are considering the direction j. Boltzmann's equation (5) multiplied by the momentum of the molecule mv_j and integrated over all velocities has the form:

$$\underbrace{\int_v m\, v_j \cdot \frac{\partial f}{\partial t}\, d^3v}_{(\mathrm{B2}_1)} + \underbrace{\int_v m\, v_j \cdot \sum_{i=1}^{3} v_i \frac{\partial f}{\partial x_i}\, d^3v}_{(\mathrm{B2}_2)} + \underbrace{\int_v m\, v_j \cdot \sum_{i=1}^{3} \frac{F_i}{\rho}\frac{\partial f}{\partial v_i}\, d^3v}_{(\mathrm{B2}_3)} = \underbrace{0}_{(\mathrm{B2}_4)}.$$

We get:

(B2$_1$)

$$\int_v m v_j \cdot \frac{\partial f}{\partial t}\, d^3v = \frac{\partial}{\partial t}\underbrace{\int_v v_j \cdot mf\, d^3v}_{u_j \cdot \rho(\vec{x},t)} = \frac{\partial(\rho u_j)}{\partial t}.$$

(B2$_2$) from:

$$\vec{v} = \underbrace{\vec{u}}_{\text{global fluid velocity}} + \underbrace{\vec{w}}_{\text{molecule's velocity fluctuation}}$$

it follows that:

$$\int_{\mathcal{V}} m\, v_j \cdot v_i \frac{\partial \mathrm{f}}{\partial x_i}\, d^3v = \frac{\partial}{\partial x_i}\int_{\mathcal{V}} \underbrace{v_j v_i}_{(w_j+u_j)(w_i+u_i)}\, \mathrm{mf}\, d^3\mathrm{v}$$

$$= \frac{\partial}{\partial x_i}\int_{\mathcal{V}} \left(w_j w_i + w_j u_i + u_j w_i + u_j u_i\right) \cdot mf\; d^3\mathrm{v}$$

$$= \frac{\partial}{\partial x_i}\int_{\mathcal{V}} u_j\, u_i \cdot mf\; d^3v + \frac{\partial}{\partial x_i}\int_{\mathcal{V}} w_j\, u_i \cdot mf\; d^3 + \frac{\partial}{\partial x_i}\int_{\mathcal{V}} u_j w_i \cdot mf\; d^3v$$

$$+ \frac{\partial}{\partial x_i}\int_{\mathcal{V}} w w_{i\,j} \cdot mf\; d^3v = \frac{\partial\left(u_j u_i \rho\right)}{\partial x_i} + \frac{\partial\left(\langle w_j u_i\rangle \rho\right)}{\partial x_i} + \frac{\partial\left(\langle w_i u_j\rangle \rho\right)}{\partial x_i} + \frac{\partial\left(\langle w_i w_j\rangle \rho\right)}{\partial x_i} = (*)$$

where $\langle x\rangle$ denotes expected value of unknown x.

Note that $\langle u_j u_i\rangle = u_j u_i$ and $\langle w_j u_i\rangle = \langle w_i u_j\rangle = 0$, because the velocity of the chaotic motion of the molecules cancels out (as long as it is in the first power). Hence:

$$(*) = \frac{\partial\left(u_j u_i \rho\right)}{\partial x_i} + \frac{\partial\left(\langle w_i w_j\rangle \rho\right)}{\partial x_i}$$

The expression $\langle w_i w_j\rangle$ is an element of second order tensor

$$\vec{\mathrm{w}} \otimes \vec{\mathrm{w}} = \begin{bmatrix} \langle \mathrm{w}_1\, \mathrm{w}_1\rangle & \langle \mathrm{w}_1\, \mathrm{w}_2\rangle & \langle \mathrm{w}_1\, \mathrm{w}_3\rangle \\ \langle \mathrm{w}_2\, \mathrm{w}_1\rangle & \langle \mathrm{w}_2\, \mathrm{w}_2\rangle & \langle \mathrm{w}_2\, \mathrm{w}_3\rangle \\ \langle \mathrm{w}_3\, \mathrm{w}_1\rangle & \langle \mathrm{w}_3\, \mathrm{w}_2\rangle & \langle \mathrm{w}_3\, \mathrm{w}_3\rangle \end{bmatrix} \tag{9}$$

The random velocities are **almost** uncorrelated, so the off-diagonal elements of the $\vec{w} \otimes \vec{w}$ tensor are close to 0. Let's separate the effects of this tensor into those related to pressure and viscosity:

$$P = \frac{1}{3}\rho(\langle w_1^2\rangle + \langle w_2^2\rangle + \langle w_3^2\rangle) \quad \text{(pressure)}$$

$$\pi_{ij} = P\delta_{ij} - \rho\langle w_i w_j\rangle \quad \text{(viscous stress tensor)}$$

With these symbols:

$$\rho\langle w_i w_j\rangle = P\delta_{ij} - \pi_{ij} \tag{10}$$

that gives:

$$\int_{\mathcal{V}} m\, v_j \cdot v_i \frac{\partial f}{\partial x_i}\, d^3v = \frac{\partial\left(u_j u_i \rho\right)}{\partial x_i} + \frac{\partial}{\partial x_i}\left(P\delta_{ij} - \pi_{ij}\right) \tag{11}$$

Henceforth:

$$\sum_{i=1}^{3}\left(\int_{\mathcal{V}} m\, v_j \cdot v_i \frac{\partial f}{\partial x_i}\, d^3v\right) = \sum_{j=1}^{3}\left(\frac{\partial\left(u_j u_i \rho\right)}{\partial x_i} + \frac{\partial}{\partial x_i}\left(P\delta_{ij} - \pi_{ij}\right)\right)$$

$$= \frac{\partial\left(u_1 u_j \rho\right)}{\partial x_1} + \frac{\partial\left(u_2 u_j \rho\right)}{\partial x_2} + \frac{\partial\left(u_3 u_j \rho\right)}{\partial x_3} + \frac{\partial\left(P\delta_{1j} - \pi_{1j}\right)}{\partial x_1} + \frac{\partial\left(P\delta_{2j} - \pi_{2j}\right)}{\partial x_2} + \frac{\partial\left(P\delta_{3j} - \pi_{3j}\right)}{\partial x_3}$$

$$= \left[\frac{\partial}{\partial x_1}, \frac{\partial}{\partial x_2}, \frac{\partial}{\partial x_3}\right] \circ \left(\left[\rho u_1 u_j, \rho u_2 u_j, \rho u_3 u_j\right] + \left[P\delta_{1j} - \pi_{1j}, P\delta_{2j} - \pi_{2j}, P\delta_{3j} - \pi_{3j}\right]\right)$$

$$= \nabla \circ \left(\rho \vec{u} u_j + \overrightarrow{P_j} - \overrightarrow{\pi_j}\right)$$

(B2$_3$) Note that from the derivative $\frac{\partial(v_j f)}{\partial v_i}$ it follows that[5]:

$$v_j \frac{\partial f}{\partial v_i} = \frac{\partial\left(v_j f\right)}{\partial v_i} - \frac{\partial v_j}{\partial v_i} \cdot f$$

Hence:

$$\int_{\mathcal{V}} m\, v_j \cdot \frac{\partial f}{\partial v_i} \frac{F_i}{\rho}\, d^3v = \frac{mF_i}{\rho} \int_{\mathcal{V}} v_j \frac{\partial f}{\partial v_i}\, d^3v =$$

$$= \frac{mF_i}{\rho} \int_{\mathcal{V}} \left(\frac{\partial\left(v_j f\right)}{\partial v_i} - \frac{\partial v_j}{\partial v_i} \cdot f\right) d^3v = \frac{mF_i}{\rho} \int_{\mathcal{V}} \left(-\delta_{ij} f\right)\, d^3v$$

because[6]:

$$\frac{mF_i}{\rho} \int_{\mathcal{V}} \frac{\partial\left(f v_j\right)}{\partial v_i}\, d^3v = \frac{\partial}{\partial v_i} \frac{F_i}{\rho} \underbrace{\int_{\mathcal{V}} v_j f\, m\, d^3v}_{u_j \cdot \rho(\vec{x},t)} = \frac{\partial\left(F_i u_j\right)}{\partial v_i} = 0$$

And:

$$\frac{\partial v_j}{\partial v_i} = \delta_{ij} = \begin{cases} 1, i = j \\ 0, i \neq j \end{cases}$$

Finally

$$\sum_{i=1}^{3}\left(\int_{\mathcal{V}} m\, v_j \cdot \frac{\partial f}{\partial v_i} \frac{F_i}{\rho}\, d^3v\right) = \sum_{i=1}^{3} \frac{mF_i}{\rho} \int_{\mathcal{V}} \left(-\delta_{ij} f\right)\, d^3v = -\sum_{i=1}^{3} \frac{F_i}{\rho} \delta_{ij} \underbrace{\int_{\mathcal{V}} m\, f\, d^3v}_{\rho(\vec{x},t)} = -F_j$$

(B2$_4$) As in the case of continuity of mass, the principle of conservation of momentum guarantees that the right-hand side of the equation disappears because the molecules do not change the total momentum in the area because of collisions.

[5] Derivative $\frac{\partial(v_j f)}{\partial v_i} = \frac{\partial v_j}{\partial v_i} \cdot f + v_j \frac{\partial f}{\partial v_i}$.

[6] The average velocity of the fluid does not depend on the velocity of the molecule.

In effect, the Boltzmann equation results in the (2) equation. the N-S equation (for j-th variable):

$$\begin{array}{ccccccc} \dfrac{\partial f}{\partial t} & + & \displaystyle\sum_{i=1}^{3} v_i \frac{\partial f}{\partial x_i} & + & \displaystyle\sum_{i=1}^{3} \frac{F_i}{\rho}\frac{\partial f}{\partial v_i} & = & \Omega(f) \\ \Downarrow & & \Downarrow & & \Downarrow & & \Downarrow \\ \dfrac{\partial(\rho\, u_j)}{\partial t} & + & \nabla \circ \left(\rho\, \vec{\mathrm{u}}_{\mathrm{j}} + \vec{\mathrm{P}}_{\mathrm{j}} - \vec{\pi}_{\mathrm{j}}\right) & + & -F_j & = & 0 \end{array}$$

4. From Boltzmann to energy equation

The following discussion will use the concept of internal energy per unit volume:

$$E = \int_{\mathcal{V}} \frac{mw^2}{2} f d^3v = \left\langle \frac{w^2}{2}\rho \right\rangle \tag{12}$$

As in the subsections above, we multiply the Boltzmann equation (5) by the kinetic energy of the molecule $\frac{mv^2}{2} = \frac{m}{2}(v_1^2 + v_2^2 + v_3^2)$ and we integrate over velocities. Hence:

$$\underbrace{\int_{\mathcal{V}} \frac{mv^2}{2} \cdot \frac{\partial f}{\partial t}\, d^3v}_{(\mathrm{B}\hat{3}_1)} + \sum_{i=1}^{3} \underbrace{\int_{\mathcal{V}} \frac{mv^2}{2} v_i \cdot \frac{\partial f}{\partial x_i}\, d^3v}_{(\mathrm{B}\hat{3}_2)} + \underbrace{\sum_{i=1}^{3} \int_{\mathcal{V}} \frac{mv^2}{2} \frac{F_i}{\rho} \cdot \frac{\partial f}{\partial v_i}\, d^3v}_{(\mathrm{B}\hat{3}_3)} = \underbrace{0}_{(\mathrm{B}\hat{3}_4)} \tag{13}$$

(B3$_1$)

$$\int_{\mathcal{V}} \frac{mv^2}{2} \cdot \frac{\partial f}{\partial t}\, d^3v = \frac{\partial}{\partial t} \int_{\mathcal{V}} \left(\frac{u^2}{2} + \vec{u} \circ \vec{w} + \frac{w^2}{2}\right) mf\; d^3v = \frac{\partial}{\partial t}\left(\frac{u^2}{2}\rho + \underbrace{\left\langle \frac{w^2}{2}\rho \right\rangle}_{E}\right)$$

because $\int_{\mathcal{V}} \vec{u} \circ \vec{w}\, mf\, d^3v = \langle uw\rho \rangle = 0$

(B3$_2$) Considerations will be made for i −th component.

$$\int_{\mathcal{V}} \frac{mv^2}{2} v_i \cdot \frac{\partial f}{\partial x_i}\, d^3v = \frac{\partial}{\partial x_i}\left(\int_{\mathcal{V}} \frac{m}{2} \sum_{k=1}^{3} (u_k + w_k)^2 (u_i + w_i) \cdot f\, d^3v\right) =$$

$$= \frac{\partial}{\partial x_i}\left(\frac{\rho}{2}\left\langle \sum_{k=1}^{3} (u_k + w_k)^2 (u_i + w_i) \right\rangle\right) =$$

$$= \frac{\partial}{\partial x_i}\left(\frac{\rho}{2}\left\langle \sum_{k=1}^{3} (u_i u_k^2 + 2u_i u_k w_k + u_i w_k^2 + w_i u_k^2 + 2u_k w_k w_i + w_i w_k^2) \right\rangle\right)$$

The expected value of the expressions in which the velocity of the chaotic motion of the molecules $\vec{w}$ occurs in the first power is 0:

$$\frac{\partial}{\partial x_i}\left(\frac{\rho}{2}\left\langle\sum_{k=1}^{3}(u_i u_k^2 + u_i w_k^2 + 2u_k w_k w_i + w_i w_k^2)\right\rangle\right) =$$

$$= \frac{\partial}{\partial x_i}\frac{\rho}{2}\left(\sum_{k=1}^{3}(u_i u_k^2 + \langle u_i w_k^2\rangle + 2\langle u_k w_k w_i\rangle + \langle w_i w_k^2\rangle)\right) =$$

$$= \frac{\partial}{\partial x_i}\frac{\rho}{2}\left(u_i u^2 + \langle u_i w^2\rangle + 2\sum_{k=1}^{3} u_k\langle w_k w_i\rangle + \langle w_i w^2\rangle\right) =$$

$$= \frac{\partial}{\partial x_i}\left(\frac{\rho u^2}{2}u_i + \underbrace{\left\langle\frac{\rho w^2}{2}\right\rangle}_{E}u_i + \sum_{k=1}^{3}\underbrace{\rho\langle w_k w_i\rangle}_{P\delta_{ik}-\pi_{ik}}u_k + \underbrace{\frac{\rho\langle w^2 w_i\rangle}{2}}_{\Phi_i}\right) =$$

$$= \frac{\partial}{\partial x_i}\left(\frac{\rho u^2}{2}u_i + Eu_i + \sum_{k=1}^{3}(P\delta_{ik} - \pi_{ik})u_k + \Phi_i\right)$$

where:

$P\delta_{ik} - \pi_{ik}$ is defined as in (10),

Φ_i – denotes conduction heat flux.

(B3$_3$) From the formula for the derivative of the product:

$$\frac{\partial(fv^2)}{\partial v_i} = \frac{\partial\left(f\cdot(v_1^2+v_2^2+v_3^2)\right)}{\partial v_i} = \frac{\partial f}{\partial v_i}\cdot v^2 + 2v_i f$$

it follows that:

$$\frac{\partial f}{\partial v_i}\cdot v^2 = \frac{\partial(fv^2)}{\partial v_i} - 2v_i f.$$

Thus:

$$\sum_{i=1}^{3}\int_{\mathcal{V}}\frac{mv^2}{2}\frac{F_i}{\rho}\cdot\frac{\partial f}{\partial v_i}\,d^3v = \sum_{i=1}^{3}\int_{\mathcal{V}}\frac{F_i}{2\rho}\cdot\left(m\frac{\partial(fv^2)}{\partial v_i} - 2mv_i f\right)d^3v =$$

$$= \frac{F_i}{2\rho}\int_{\mathcal{V}}\left(\nabla_{\vec{v}}mfv^2 - \sum_{i=1}^{3}2mv_i f\right)d^3v = \frac{F_i}{2\rho}\int_{\mathcal{V}}\nabla_{\vec{v}}\,mfv^2\,\mathrm{d}^3v - \sum_{i=1}^{3}\frac{F_i}{\rho}\int_{\mathcal{V}}mv_i f\,\mathrm{d}^3v =$$

$$= \frac{F_i}{2m}\underbrace{\oiint_{\partial\mathcal{V}} fv^2\vec{n}\,\mathrm{d}S}_{\text{Divergence Theorem}} - \sum_{i=1}^{3}\frac{F_i}{\rho}\rho u_i = -\sum_{i=1}^{3}F_i u_i$$

Integral $\oiint_{\partial\mathcal{V}} fv^2\mathcal{V}\vec{n}\,\mathrm{d}S = 0$ since there is no outflow of molecules from the $\mathcal{V}$ region (in phase space). Hence, the total energy equation, derived from the Boltzmann equation, takes the form:

$$\frac{\partial}{\partial t}\left(\frac{u^2}{2}\rho + E\right) + \sum_{i=1}^{3}\frac{\partial}{\partial x_i}\left(\frac{\rho u^2}{2}u_i + Eu_i + \sum_{k=1}^{3}(P\delta_{ik} - \pi_{ik})u_k + \Phi_i\right) = \sum_{i=1}^{3}F_i\,u_i \qquad (14)$$

To express the above equation in a form that includes only quantities related to the internal motion of the molecules, let us return to the momentum equation:

$$\frac{\partial}{\partial t}(\rho u_i) + \sum_{k=1}^{3} \frac{\partial}{\partial x_k}(\rho u_i u_k + P\delta_{ik} - \pi_{ik}) = F_i$$

Calculating the derivatives of the products, the equation above, one can write:

$$\underline{u_i \frac{\partial \rho}{\partial t}} + \rho \frac{\partial u_i}{\partial t} + \sum_{k=1}^{3} \left(\frac{\partial \rho u_k}{\partial x_k} u_i + \underline{\frac{\partial u_i}{\partial x_k} \rho u_k} \right) + \sum_{k=1}^{3} \frac{\partial}{\partial x_k}(P\delta_{ik} - \pi_{ik}) = F_i$$

The underlined components, according to the continuity equation (2), add up to 0. Therefore:

$$\rho \frac{\partial u_i}{\partial t} + \sum_{k=1}^{3} \left(\frac{\partial \rho u_i}{\partial x_k} u_k \right) = F_i - \sum_{k=1}^{3} \frac{\partial}{\partial x_k}(P\delta_{ik} - \pi_{ik}) . \tag{15}$$

Let us revisit the momentum equation again, this time multiplying it by the velocity u_i:

$$u_i \frac{\partial}{\partial t}(\rho u_i) + \sum_{k=1}^{3} u_i \frac{\partial}{\partial x_k}(\rho u_i u_k + P\delta_{ik} - \pi_{ik}) = F_i u_i$$

Using the derivative of the product $\frac{\partial(\rho u_i)}{\partial t}$, this equation can be written in the form:

$$\frac{\partial \rho u_i^2}{\partial t} - \underline{\rho u_i \frac{\partial u_i}{\partial t}} + \sum_{k=1}^{3} \left(\frac{\partial \rho u_i^2 u_k}{\partial x_k} - \underline{\rho u_i u_k \frac{\partial u_i}{\partial x_k}} \right) + \sum_{k=1}^{3} u_i \frac{\partial}{\partial x_k}(P\delta_{ik} - \pi_{ik}) = F_i u_i .$$

As a result of adding equation above to equation (15) multiplied by u_i underlined components will cancel out. Finally, we get:

$$\frac{\partial \rho u_i^2}{\partial t} + \sum_{k=1}^{3} \frac{\partial \rho u_i^2 u_k}{\partial x_k} = 2F_i u_i - 2\sum_{k=1}^{3} u_i \frac{\partial}{\partial x_k}(P\delta_{ik} - \pi_{ik}).$$

Finally:

$$\frac{\partial}{\partial t}\left(\frac{\rho u_i^2}{2} \right) + \sum_{k=1}^{3} \frac{\partial}{\partial x_k}\left(\frac{\rho u_i^2 u_k}{2} \right) = F_i u_i - \sum_{k=1}^{3} u_i \frac{\partial}{\partial x_k}(P\delta_{ik} - \pi_{ik}) \tag{16}$$

Summing up the variants of the equation (16) corresponding to each direction, we get:

$$\frac{\partial}{\partial t}\left(\frac{\rho(u_1^2 + u_2^2 + u_3^2)}{2} \right) + \sum_{k=1}^{3} \frac{\partial}{\partial x_k}\left(\frac{\rho(u_1^2 + u_2^2 + u_3^2)u_k}{2} \right) =$$

$$= F_1 u_1 + F_2 u_2 + F_3 u_3 - \sum_{i=1}^{3}\sum_{k=1}^{3} u_i \frac{\partial}{\partial x_k}(P\delta_{ik} - \pi_{ik}),$$

which is easily simplified to:

$$\frac{\partial}{\partial t}\left(\frac{\rho u^2}{2} \right) + \sum_{k=1}^{3} \frac{\partial}{\partial x_k}\left(\frac{\rho u^2 u_k}{2} \right) = \sum_{i=1}^{3} F_i u_i - \sum_{i=1}^{3}\sum_{k=1}^{3} u_i \frac{\partial}{\partial x_k}(P\delta_{ik} - \pi_{ik}) . \tag{17}$$

Using the product rule derivative

$$\frac{\partial\left((P\delta_{ik}-pi_{ik})u_i\right)}{\partial x_k}=u_i\frac{\partial}{\partial x_k}(P\delta_{ik}-\pi_{ik})+(P\delta_{ik}-\pi_{ik})\frac{\partial u_i}{\partial x_k}$$

we get:

$$\frac{\partial}{\partial t}\left(\frac{\rho u^2}{2}\right)+\sum_{k=1}^{3}\frac{\partial}{\partial x_k}\left(\frac{\rho u^2 u_k}{2}\right)=\sum_{i=1}^{3}F_i\,u_i-\sum_{i=1}^{3}\sum_{k=1}^{3}\left(\frac{\partial(P\delta_{ik}-\pi_{ik})u_i}{\partial x_k}-(P\delta_{ik}-\pi_{ik})\frac{\partial u_i}{\partial x_k}\right)$$

Subtracting the above equation from the equation (14) we are left with:

$$\frac{\partial E}{\partial t}+\sum_{i=1}^{3}\frac{\partial E u_i}{\partial x_i}+\sum_{i=1}^{3}\sum_{k=1}^{3}\left((P\delta_{ik}-\pi_{ik})\frac{\partial u_i}{\partial x_k}\right)+\sum_{i=1}^{3}\frac{\partial\Phi_i}{\partial x_i}=0.$$

Taking the symbol $\Psi=\sum_{i=1}^{3}\sum_{k=1}^{3}\pi_{ik}\frac{\partial u_i}{\partial x_k}$ as rate of viscous dissipation the internal energy equation is obtained:

$$\frac{\partial E}{\partial t}+\sum_{i=1}^{3}\frac{\partial E u_i}{\partial x_i}=-\sum_{i=1}^{3}\sum_{k=1}^{3}P\,\delta_{ik}\frac{\partial u_i}{\partial x_k}+\Psi-\sum_{i=1}^{3}\frac{\partial\Phi_i}{\partial x_i}$$

which can be converted to (3).

5. LBM algorithm overview

The main purpose of the considerations presented so far in the paper is to show how to obtain the Navier-Stokes equations from the Boltzmann equation. Each of the conservation laws was obtained by integrating over all velocities the Boltzmann equation, which was previously multiplied by the appropriate quantities.

The same principle also guides the idea of the Lattice Boltzmann Method. The discretization of the Boltzmann equation (in the velocity, space, and time domains) leads to the construction of an iterative procedure describing the evolution of a discrete variant of the distribution function, i.e., the flow of mesoscopic populations in the lattice.

The main idea behind LBM is to write the Boltzmann equation in a discrete form. Discretization begins with the construction of a discrete mesh (lattice) that divides the computational domain into cells. Only q directions are considered in each cell. The discrete distribution function is analogous to the continuous counterpart in the sense that from its moments we can recover density, momentum, and energy, but is only defined on a discrete finite set of velocities, positions, and time instances. The values of the distribution function defined on certain nodes at a given instance of time are called mesoscopic populations. Each of the finite number of populations has velocity in one of q allowed directions. The population assigned to node ${}_jx$ and having velocity in direction i is denoted by ${}_if({}_jx)$. The lattice model

determines how many populations with discrete velocity vectors in different directions will be assigned to a lattice node. In two-dimensional simulations, the D2Q9 lattice is most often used, in which there are 9 populations at each node. An exemplary node of the D2Q9 lattice (together with the method of numbering velocities) is shown in Fig. 1. The population with zero velocity is resting in the middle of the node. Symbolically, the fact that populations can be of different sizes is indicated by the different lengths of the corresponding arrows.

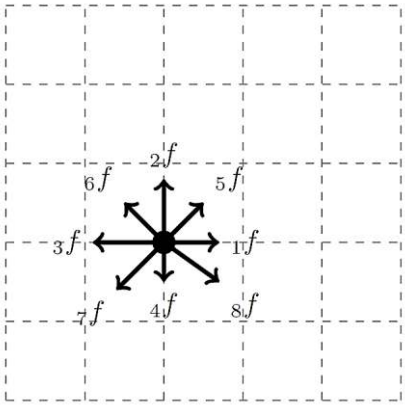

Figure 1. Example of lattice populations.

The evolution of the i-th population is described by the formula:

$$ {}_{i}f({}_{j}x + \overrightarrow{{}_{i}v}\Delta t, t + \Delta t) = {}_{i}f({}_{j}x, t) + \Omega({}_{i}f({}_{j}x, t)) \tag{18} $$

Note that since the right side of the equation (18) depends only on the values of the functions at points in the space, calculations can be carried out simultaneously for all points in space (which significantly reduces the time for performing simulations). In LBM this step in calculations is called *a collision*. The left side of the equation (18) does require knowledge of the value of the distribution function at neighboring points (*a propagation*), but since this step only involves shifting the previously calculated values to other positions, once the variables are properly arranged in the computer's memory, it does not significantly reduce computing performance. The collision and the propagation together form one iteration step for the ${}_{i}f$ population.

It should be emphasized that the equation (18) applies only to the behavior of the population inside the flow domain. A separate treatment is required for boundary conditions, which, due to the topic of the paper, will be omitted here.

If we know the values of the discrete distribution function at each node and for each direction (population), the macroscopic quantities of interest can be determined using the corresponding weighted sums.

And so:

$$ \rho({}_{j}x, t) = \sum_{i=1}^{N} {}_{i}f({}_{j}x, t) $$

$$\rho({}_j x, t)\vec{u}({}_j x, t) = \sum_{i=1}^{N} {}_i \vec{v}({}_j x, t_i) f({}_j x, t)$$

where: N is the number of populations in the adopted lattice model.

Note that in LBM, the density is obtained analogously to that in (8) by summing the discrete distributions of all populations. The momentum can be determined as the effect of multiplying the discrete values of f by the population velocities (similar to the derivation of the momentum conservation principle equations).

Just as the macroscopic variables are the corresponding moments of the distribution function f with respect to the velocity $\vec{v}$, the same quantities can be determined as sums of discrete values of f obtained by the Lattice Boltzmann Method. A detailed consideration of LBM with a discussion of the implementation of boundary conditions can be found in (Krüger, 2016).

6. Conclusions

The Boltzmann equation and the Navier-Stokes equations describe different aspects of fluid dynamics and are not directly comparable in generality. Because the Boltzmann equation considers the behavior of individual fluid molecules and their collisions, it is considered a more fundamental description of the flow.

The fact that this equation is more general than the N-S equations is one of the foundations of the Boltzmann lattice method. In LBM, instead of equations describing fluid dynamics on a macroscopic scale, a fluid consisting of fictitious mesoscopic populations is modeled, each of which is associated with a specific lattice node and has a specific velocity. Discrete values of the population density function determined in LBM are used to find quantities characteristic of fluid dynamics. Literature often emphasizes the advantages of calculations using LBM, but it is difficult to find a justification for the relationship between equations of a different nature, such as the Boltzmann equation and the equations of conservation of mass, momentum and energy.

The article presents detailed derivations of the continuity equation, the Navier-Stokes equations, and the energy equation from the Boltzmann equation. The work was aimed at systematizing and, above all, detailing the calculations showing the interrelationships between these equations. The conditions in which the more general Boltzmann equations are reduced to one of the equations describing flows on a macroscopic scale help in understanding how the results obtained in LBM are used in calculations competing with standard CFD.

References

1. Basu, S.K. (2020). A fully coupled hybrid lattice Boltzmann and finite difference method-based study of transient electrokinetic flows. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*.
2. Bhairapurada, K.A. (2022). A Lattice-Boltzmann study of premixed flames thermo-acoustic instabilities. *Combustion and Flame, 240,* 112049.
3. Bhatnagar, P.L. (1954). A Model for Collision Processes in Gases. I. Small Amplitude Processes in Charged and Neutral One-Component Systems. *Phys. Rev.*, pp. 511-525.
4. Grad, H. (1949b). Note on n-dimensional hermite polynomials. *Communications on Pure and Applied Mathematics*, pp. 325-330.
5. Grad, H. (1949a). On the kinetic theory of rarefied gases. *Communications on Pure and Applied Mathematics*, pp. 331-407.
6. Hardy, J.A. (1973a). Time Evolution of a Two-Dimensional Classical Lattice System. *Physical Review Letters*, *Vol. 31, No. 5,* pp. 276-279.
7. Hardy, J.A. (1973b). Time evolution of a two-dimensional model system. I. Invariant states and time correlation functions. *Journal of Mathematical Physics, 14*, pp. 1746-1759.
8. Krüger, T.A. (2016). *The Lattice Boltzmann Method - Principles and Practice*.
9. Li, L. (2020). Lattice Boltzmann Method for Fluid-Thermal Systems: Status, Hotspots, Trends and Outlook. *IEEE Access*.
10. Li, Z. (2016). *Multiscale Thermal Transport in Energy Systems.* Hauppauge, New York: Nova Science Publishers, Inc.
11. Li-Shi, L. (2000). The lattice-gas and lattice Boltzmann methods: past, present, and future. *Proceedings of the International Conference on Applied Computational Fluid Dynamics*, pp. 52-83.
12. Miled, O. (2020). Numerical investigation of porous stack for a solar-powered thermoacoustic refrigerator. *Advances in Mechanical Engineering, 12(6)*.
13. Shu, F. (1991). *The Physics of Astrophysics: Gas dynamics.* Sausalito, California: University Science Books.
14. Taileb, S.M. (2022). Lattice-Boltzmann modeling of lifted hydrogen jet flames: A new model for hazardous ignition prediction. *Combustion and Flame, 245(0010-2180),* 112317.
15. Xu, Z. (2021). Recent Advances of Lattice Boltzmann Method in Microfluidic numerical Simulation. *Journal of Physics: Conference Series, 1,* 012084.
16. Zhao, S. (2020). Toward fully conservative hybrid lattice Boltzmann methods for compressible flows. *Physics of Fluids, 32,* 126118.

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THE ROLE OF ESG REPORTING IN MERGERS AND ACQUISITIONS

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Purpose: The aim of this article is to examine the importance of ESG *(Environmental, Social, Governance)* reporting in investor decisions during mergers and acquisitions.
Design/methodology/approach: The article employs a literature review and analysis of available data on ESG indicators. The analysis was conducted in two main stages: a review of scholarly literature on the impact of ESG indicators on M&A, and an analysis of financial data of companies involved in M&A processes, using data from reputable industry databases.
Findings: The analysis shows that companies with high levels of ESG reporting achieve better financial outcomes following M&A processes. These companies gain greater investor trust, resulting in improved financing terms and financial stability.
Research limitations/implications: The article does not account for potential differences arising from regional ESG regulations, which may be a subject of further research. Limitations also include a lack of data from certain economic sectors.
Practical implications: The study's findings indicate that integrating ESG into M&A strategy enables companies not only to build long-term value but also to reduce operational and regulatory risk, making them more attractive to investors.
Social implications: ESG reporting plays a significant role in promoting social responsibility and sustainable development. It also supports positive relationships with stakeholders, contributing to an improved quality of life and increased social awareness.
Originality/value: This article provides insight into the growing importance of ESG in M&A processes, particularly in terms of its impact on long-term financial outcomes and enterprise value.
Keywords: ESG, mergers and acquisitions, sustainable development, enterprise value, social responsibility.
Category of the paper: Research paper.

1. Introduction

Modern enterprises operating in a globalized economy face increasing pressure to conduct business in accordance with the principles of sustainable development and corporate social responsibility (CSR). Rising social awareness and new regulatory frameworks are prompting

investors and management teams to increasingly incorporate ESG (Environmental, Social, Governance) factors in investment decisions, which serve as indicators of an organization's impact on the environment, society, and transparency of governance (Fatemi, Glaum, Kaiser, 2018; Kozłowska-Makóś, 2020). As noted by Friede, Busch, and Bassen (2015), integrating ESG into financial decisions not only helps minimize investment risk but also supports long-term enterprise value.

ESG reporting, as a tool for transparency and accountability, is gaining recognition as a critical criterion for evaluating companies, particularly in the context of mergers and acquisitions (M&A). Investors seeking responsible investment options expect companies to uphold high ESG standards, which can help mitigate risks associated with integration and future operations after the transaction is completed (Khan, Serafeim, Yoon, 2016; Eccles, Stroehle, 2018). ESG reports provide information on an organization's actions in environmental protection, ethical practices, and transparent governance, which can enhance a company's attractiveness to potential investors and decision-makers (Boffo, Patalano, 2020; Kozłowska-Makóś, 2023).

Studies indicate that high ESG scores can positively impact a company's financial performance post-M&A, making ESG a crucial element in evaluating integration processes (Clark, Feiner, Viehs, 2015; Gillan, Koch, Starks, 2021; Kozłowska-Makóś, 2018). As Wójcik and Ioannou (2020) observe, incorporating sustainable development into M&A strategy not only strengthens a company's market position but also contributes to creating added value.

This article aims to examine the role of ESG reporting in M&A processes and its impact on investment decisions. By analyzing ESG data from companies involved in M&A and investor opinions, this study addresses whether a high standard of ESG reporting truly influences transaction perception and value.

2. Methods

To achieve the stated research objective, a wide range of sources and available data were utilized to analyze the impact of ESG reporting on investment decisions in merger and acquisition processes. The analysis was conducted in two main stages: a literature review and an analysis of available data on ESG indicators.

The first step of the study was a review of scientific and industry literature, covering publications from the last five years on the impact of ESG indicators on M&A processes. To conduct the review analysis, reputable databases such as JSTOR, ScienceDirect, and Google Scholar were used, focusing on scientific articles, industry reports, and regulatory documents. The literature review enabled the identification of key themes and trends associated with the application of ESG in M&A, and highlighted the ESG indicators most frequently analyzed by

investors. Additionally, industry reports and market analyses were used to obtain a fuller picture of current practices.

In the second stage, available data on ESG indicators and financial performance of companies involved in M&A processes in recent years were analyzed. These data were sourced from publicly available resources, such as ESG and financial reports published by companies, as well as industry databases, including Bloomberg and Thomson Reuters. The focus was on key ESG indicators, covering environmental performance (e.g., CO_2 emissions, resource management), social performance (e.g., working conditions, community engagement), and governance (e.g., management transparency, governance structure). The goal of this analysis was to identify correlations between ESG indicators and financial performance following the completion of M&A transactions.

In the qualitative analysis, content analysis was employed to identify key themes and trends related to ESG implementation in M&A processes. Additionally, basic statistical methods, such as correlation analysis, were used to illustrate general relationships between ESG indicators and financial outcomes.

3. Results

The results of the literature analysis and available data indicate a significant impact of ESG indicators on M&A processes as well as on the financial performance of companies after transaction completion. The findings are presented in three main areas: the impact of individual ESG indicators on M&A, the variation in financial outcomes depending on the level of ESG reporting, and the key motives and trends related to ESG in the M&A context.

3.1. The Impact of ESG indicators on M&A processes

A review of the literature shows that each of the key ESG indicators – Environmental, Social, and Governance – plays a significant role in investors' decisions, although their importance varies depending on the sector of activity (Fatemi, Glaum, Kaiser, 2018; Khan, Serafeim, Yoon, 2016; Kotsantonis, Pinney, Serafeim, 2016). Specifically:

- environmental ESG indicators – factors related to CO_2 emissions and energy efficiency are crucial in industrial and energy sectors, which are exposed to regulatory and reputational risks due to their environmental impact (Eccles, Stroehle, 2018; Schaltegger, Burritt, 2018);
- social ESG indicators – elements such as working conditions and relationships with local communities are particularly important in sectors with a high proportion of employees, such as the service sector. These indicators positively impact employee loyalty and customer perception (Kozłowska-Makóś, 2020; Turban, Greening, 1997);

- governance ESG indicators – transparency and quality of governance are valued by investors across all sectors, influencing the level of trust in the company and stability in the integration process following a merger or acquisition (Clark, Feiner, Viehs, 2015; Gillan, Koch, Starks, 2021).

In conclusion, each ESG indicator affects different aspects of the M&A process. Environmental indicators increase regulatory security, social indicators strengthen stakeholder relations and loyalty, and governance indicators enhance trust and transparency. This differentiation in the role of ESG indicators makes them essential for the long-term value and stability of M&A transactions (Table 1).

Table 1.
The importance of ESG indicators in various economic sectors in M&A processes

ESG Indicator	Sectors of particular importance	Key ESG indicators	Impact on M&A processes	Financial benefits
Environmental	industrial, energy	CO_2 emissions, energy usage	reduction in costs and regulatory risks	lower operating costs, regulatory compliance
Social	service	working conditions, equal opportunities	increased customer and employee loyalty	reduced employee turnover, positive public image
Governance	all sectors	transparency, governance structure	improved transparency and reputation	greater investor trust, lower financing costs

Source: own elaboration based on: Fatemi, Glaum, Kaiser (2018); Khan, Serafeim, Yoon (2016); Clark, Feiner, Viehs (2015); Turban, Greening (2017); Servaes, Tamayo (2013); Schaltegger, Burritt (2018); Grewatsch, Kleindienst (2017).

As shown by the presented data, ESG indicators – Environmental, Social, and Governance – play a significant role in M&A processes, with their importance varying depending on the sector of activity. This differentiation highlights the need for further analysis to determine how ESG integration affects the financial performance of companies following M&A transactions.

3.2. The importance of ESG reporting for financial performance in M&A processes

Available data suggest that companies with a high level of ESG reporting achieve better financial performance after completing M&A transactions compared to companies with low ESG scores. These outcomes include an increase in market value and improved operational results, which may be a result of enhanced reputation and greater investor trust (Clark, Feiner, Viehs, 2015; Gillan, Koch, Starks, 2021; Servaes, Tamayo, 2013). An analysis of industry reports indicates that, in particular, companies transparent in governance and those with strong environmental performance achieve higher ROI and lower financing costs (Boffo, Patalano, 2020; Eccles, Ioannou, Serafeim, 2014) (Figure 1).

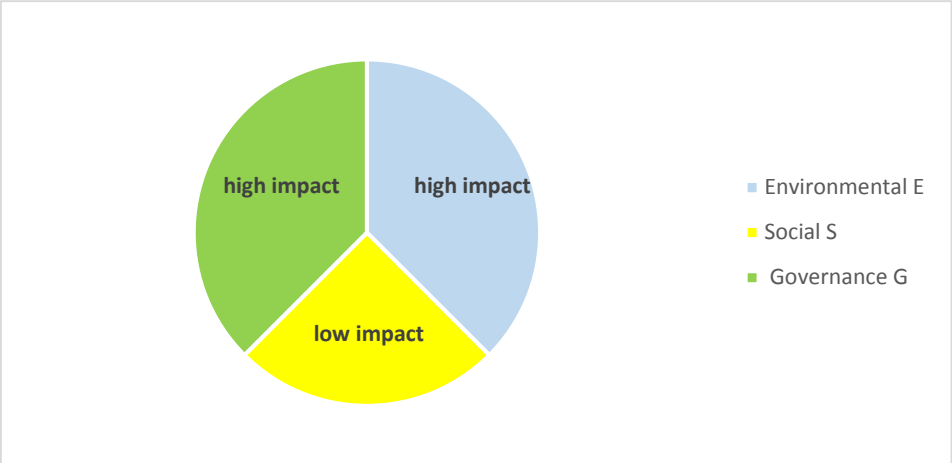

Figure 1. The Impact of ESG indicators on financial performance after M&A.

Source: own elaboration based on: Clark, Feiner, Viehs (2015); Servaes, Tamayo (2013); Boffo, Patalano (2020).

The analysis of the relationship between ESG indicators and financial performance suggests that each ESG factor brings unique value to the financial outcomes of companies post-M&A. Environmental, Social, and Governance indicators have varied significance depending on the sector of activity; however, collectively, they contribute to building sustainable market value and financial stability for the company.

Considering these findings, it is valuable to examine the key motives and trends that encourage companies to integrate ESG into their M&A strategy, as well as to assess the opportunities and challenges associated with this process.

3.3. Key motives and trends related to ESG in M&A processes

Qualitative analysis allowed for the identification of key motives and trends associated with implementing ESG in M&A processes. Investors are increasingly demanding ESG reporting as part of growth strategies, which can be observed in numerous M&A transactions where ESG becomes an integral part of assessing potential benefits (Wójcik, Ioannou, 2020; Friede, Busch, Bassen, 2015; Eccles et al., 2014). Additionally, there has been a rise in the number of mergers and acquisitions in which entities commit to eco-friendly investments to meet new regulatory requirements and stakeholder expectations (Grewatsch, Kleindienst, 2017).

The key motives for implementing ESG in an M&A strategy include:

- minimizing regulatory risk - companies become more proactive in adapting to changing environmental laws and regulations, helping them avoid potential sanctions and fines,
- building investor and stakeholder trust - transparency and adherence to ESG values attract investors seeking sustainable investments,
- increasing competitiveness and innovation - companies that integrate ESG gain an advantage through new technologies and eco-friendly solutions that can reduce costs and improve operational efficiency.

Despite numerous benefits, the process of implementing ESG also presents challenges, such as additional implementation costs and the need to adjust management structures. To better understand the impact of ESG on M&A, Table 2 presents a SWOT analysis that illustrates the strengths and weaknesses, as well as the opportunities and threats, associated with integrating ESG into company strategy in M&A processes.

Table 2.
SWOT analysis for ESG integration in M&A

Element	Description
Strengths	- increased investor and stakeholder trust - enhanced reputation and positive public image - improved operational efficiency through eco-friendly and social initiatives
Weaknesses	- potential costs of ESG implementation - integration challenges and adapting organizational culture post-M&A - long-term commitment required for monitoring and reporting ESG practices
Opportunities	- increase in market value and attractiveness for ESG-focused investors - opportunity for better risk management and regulatory compliance - development of innovations through investments in eco-friendly technologies
Threats	- rapid regulatory changes and rising formal requirements - high stakeholder expectations that may be challenging to meet - risk of greenwashing accusations, or being perceived as engaging in superficial ESG efforts

Source: own elaboration based on: Wójcik, Ioannou (2020); Grewatsch, Kleindienst (2017); Eccles et al. (2014).

The analysis indicates a strong correlation between ESG indicators and post-M&A financial performance, particularly in terms of reputation and regulatory compliance. Companies that implement high ESG standards enjoy greater investor trust, which translates into financial stability and improved performance following a merger or acquisition.

4. Discussion

The analysis results indicate significant benefits stemming from the integration of ESG indicators in M&A processes. Companies with a high level of ESG reporting achieve better financial outcomes, as evidenced by both the financial results of the analyzed companies and data from the literature (Clark, Feiner, Viehs, 2015; Servaes, Tamayo, 2013; Boffo, Patalano, 2020). The transparency provided by ESG reporting fosters increased investor trust, which, in turn, translates into reduced capital risk and better financing terms. These findings align with the research of Wójcik and Ioannou (2020), which suggests that companies with high ESG standards are more likely to achieve financial stability post-M&A.

At the same time, integrating ESG into M&A processes presents challenges, particularly in managing implementation costs and adapting organizational structures. As Grewatsch and Kleindienst (2017) highlight, high ESG requirements may generate additional costs; however,

the benefits of implementing them—including improved reputation and increased market value—often outweigh these expenditures. These findings suggest that implementing ESG should be viewed as a strategic investment that allows companies to build long-term value and sustainable competitive advantage.

The SWOT analysis confirms that ESG integration is essential for building value post-M&A but requires management flexibility and the ability to respond to changing stakeholder expectations. Opportunities, such as improved reputation and increased market value, can be realized if the entity effectively manages challenges such as costs and the need to adapt to regulatory requirements.

In summary, implementing ESG in M&A processes is crucial for both investors and management, enabling financial stability and the creation of added value. ESG integration not only meets stakeholder expectations but also facilitates companies' adaptation to evolving regulatory and social conditions. These results suggest that future research should focus on a more detailed understanding of the mechanisms that enable companies to maximize value through ESG strategies, especially in the context of global challenges such as climate change and rising social inequalities.

5. Summary

This article highlights the growing role of ESG (Environmental, Social, Governance) indicators in M&A processes. The conducted analyses indicate that companies with high levels of ESG reporting achieve better financial results and gain greater investor trust, which can translate into long-term stability and increased market value. Including ESG indicators in M&A strategy helps to minimize operational and regulatory risk, which, in the context of dynamic changes in the legal and social environment, becomes an essential element of competitive advantage.

Both the results of the literature analysis and available data suggest that key ESG indicators—environmental, social, and governance—have varied significance depending on the sector of activity. In particular, environmental and governance indicators play an essential role in sectors requiring high regulatory compliance and operational transparency. Social indicators, although moderate in impact, support stakeholder loyalty and enhance the company's image, facilitating effective post-merger integration.

The SWOT analysis conducted in the article indicates that ESG integration presents both opportunities and challenges for companies. Increased investor trust, improved reputation, and better risk management represent ESG's strengths, while implementation costs, integration challenges, and the risk of greenwashing may pose obstacles for companies. However, with

appropriate management of these factors, ESG can become a key growth strategy component that supports building long-term value and sustainable development.

In conclusion, implementing ESG in M&A processes is a step towards modern, responsible management that addresses the needs of the contemporary market and stakeholder expectations. The article suggests that further research on ESG practices should focus on a more detailed understanding of the mechanisms that enable entities to maximize market value and sustainable development in the long term.

References

1. Boffo, R., Patalano, R. (2020). *ESG Investing: Practices, Progress and Challenges. OECD*. Retrieved from: https://www.oecd-ilibrary.org/docserver/5504598c-en.pdf?expires=1731091405&id=id&accname=guest&checksum=A28BF525158408FB3ABD70F230560584, 8.11.2024.
2. Clark, G.L., Feiner, A., Viehs, M. (2015). *From the Stockholder to the Stakeholder: How Sustainability Can Drive Financial Outperformance*. University of Oxford and Arabesque Partners.
3. Eccles, R.G., Stroehle, J.C. (2018). Exploring Social Origins in the Construction of ESG Measures. *Journal of Applied Corporate Finance, 30(2)*, pp. 47-55.
4. Fatemi, A., Glaum, M., Kaiser, S. (2018). ESG Performance and Firm Value: The Moderating Role of Disclosure. *Global Finance Journal, 38*, pp. 45-64, doi: 10.1016/j.gfj.2017.03.001.
5. Friede, G., Busch, T., Bassen, A. (2015). ESG and Financial Performance: Aggregated Evidence from More than 2000 Empirical Studies. *Journal of Sustainable Finance & Investment, 5(4)*, pp. 210-233, Retrieved from: https://doi.org/10.1080/20430795.2015.1118917.
6. Gillan, S.L., Koch, A., Starks, L.T. (2021). Firms and Social Responsibility: A Review of ESG and CSR Research in Corporate Finance. *Journal of Corporate Finance, 66,* 101889.
7. Grewatsch, S., Kleindienst, I. (2017). When does it pay to be good? Moderators and mediators in the corporate sustainability–corporate financial performance relationship: A critical review. *Journal of Business Ethics, 145(2)*, pp. 383-416.
8. Khan, M., Serafeim, G., Yoon, A. (2016). Corporate Sustainability: First Evidence on Materiality. *The Accounting Review, 91(6)*, pp. 1697-1724.
9. Kotsantonis, S., Pinney, C., Serafeim, G. (2016). ESG integration in investment management: Myths and realities. *Journal of Applied Corporate Finance, 28(2)*, pp. 1-16.

10. Kozłowska-Makóś, D. (2020). The importance of corporate social responsibility in shaping transfer prices. In: J. Krasodomska, K. Chłapek, S. Krajewska (Eds.), *Accounting, reporting and auditing* (pp. 112-119). Warszawa: Difin.
11. Kozłowska-Makóś, D., Emerling, I. (2023). Transactions with related entities in the light of tax solutions and CSR goals. *Zeszyty Naukowe Politechniki Śląskiej. Organizacja i Zarządzanie, 186*, pp. 255-267.
12. Kozłowska-Makóś, D., Kluzek, M. (2018). Społeczna odpowiedzialność biznesu a zachowania przedsiębiorstw w zakresie opodatkowania. Finanse i rachunkowość na rzecz zrównoważonego rozwoju. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu, no. 532*, pp. 185-193.
13. Schaltegger, S., Burritt, R. (2018). Business cases and corporate engagement with sustainability: Differentiating ethical motivations. *Journal of Business Ethics, 147(2)*, pp. 241-259, doi: 10.1007/s10551-015-2938-0.
14. Servaes, H., Tamayo, A. (2013). The impact of corporate social responsibility on firm value: The role of customer awareness. *Management Science, 59(5)*, pp. 1045-1061.
15. Turban, D.B., Greening, D.W. (2017). Corporate social performance and organizational attractiveness to prospective employees. *Academy of Management Journal, 40(3)*, pp. 658-672.
16. Wójcik, D., Ioannou, I. (2020). *Environmental and Social Issues in Finance*. New York/ London: Routledge.

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STRUKTURALIZATION OF MARKETING INFORMATION SYSTEMS IN DENTAL MEDICAL ENTIETIES

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Purpose: The aim of the article is to create a model of a marketing information system that will make it easier for medical entities to choose information/data that should be tracked and collected in the marketing sphere, which will consequently translate into the effective sale of medical services.
Design/methodology/approach: Literature studies, the document research method and expert knowledge, were used in the paper**.**
Findings: The work catalogs the main sets of information that should be collected in order to effectively manage the marketing area.
Practical implications: A model for structuring the marketing information system operating in a dental entity will help in collecting data necessary to make strategic, tactical and operational decisions regarding the marketing area.
Originality/value: A model for structuring the marketing information system operating in a dental entity.
Keywords: information system, marketing information system, dentist entities.
Category of the paper: Research paper.

1. Introduction

Entities providing medical services, like other business entities, must operate effectively if they want to stay on the market. This is conditional, among other things, on access to appropriate information at the appropriate time, place and form. Information reaching the company, both from the market environment and from the company itself, must be appropriately structured in terms of the functions and tasks of the system, the type of decisions made, and the structure of processes occurring in a medical entity, such as a dental office. A properly structured information system ensures proper ordering of the collection and subsequent use of information for decision-making purposes. A properly constructed system for generating, transmitting and processing data gives the company the opportunity to reduce uncertainty in operation and better adapt to dynamically changing environmental conditions.

The aim of the article is to create a model of a marketing information system that will make it easier for medical entities to choose information/data that should be tracked and collected in the marketing sphere, which will consequently translate into the effective sale of medical services.

2. Information systems in enterprise

The activity of the enterprise, including a medical entity such as a dental office, is aimed at achieving the goals set by it. It is believed that the primary goal of an enterprise is to strive to increase its value (Żurek, 2016). This goal is achieved through the skillful operation of the company in a competitive market, which contributes to increasing its market share, and in turn to increasing the book value of the company and achieving maximum profit (Wachowiak et al., 2006). Achieving the main goal results from the degree of implementation of auxiliary (partial) goals (Dołhasz, 2009). Partial goals are the result of the complexity of the company's structure, they are related to various areas of its activity, and therefore require detailed, individual assessments in terms of their place and functions in the company's structure.

However, in order to achieve these goals, access to full information on the state of the enterprise and its environment is needed, which will be used in the decision-making process (Żurek, 2016). Information is the basis for the functioning of every economic facility in the modern world. The concept of information is understood as a factor that increases knowledge about the enterprise and its environment. Information is defined as one of the most valuable management resources, which is the basis for both operational, tactical and strategic decisions made in the enterprise (Żurek, 2016).

For the efficient functioning of the enterprise, two sources of information are used (Nowicki, 2007):

- coming from the external environment - regarding, among others, the current legal status, political and economic situation of the country, introduced medical innovations, competition behavior,
- coming from the internal environment of the company - information regarding patient preferences, existing documentation (reports), business records, information from employees, and tests performed. Tables, figures and formulas – continuous numbering in the text.

However, in times of universal access to information, and even an avalanche of information flowing into the company, related to, among others, Due to the turbulence of the environment and the development of computerization, it becomes impossible for entities offering dental services to function on the basis of random, disordered or redundant information. In order to rationalize the circulation of data and avoid the so-called information noise, it becomes

necessary to organize a coherent system called the information system in which the following will be determined (Nowicki, 2007):

- information needs of users,
- ability to access appropriate sources of information,
- places of information selection and processing,
- time of information delivery, its scope and form adequate to the user's needs.

Managers and managers performing management functions expect information about specific characteristics, at a specific place and time, because the accuracy of decisions determines the efficiency of the functioning of a medical facility. The better the quality of information, the better the quality of decisions (Nowak, 2014). The quality of management information is determined by its functional features: completeness, availability, content, required form, selectivity, reliability, and degree of formalization. In theoretical approaches, these characteristics are summarized in the term "objective information supply". It means the amount and quality of information that limits uncertainty in management (Szałucki, 2017). Access to this type of data can only be provided to managers/managers of a medical unit by an individually tailored information system. We can talk about the existence of an information system in an enterprise when there is always a specific (more or less routinized) procedure for using data (in terms of collecting, processing and transmitting it). An information system is a set of rules, methods and procedures for creating, transmitting, processing and storing information for the purpose of managing an economic entity. The information system creates an information system responsible for efficient communication between individual internal units of the enterprise, as well as between the enterprise and its environment (Nowicki, 2007).

By information system we understand any and only such system that performs at least one of the following functions (Combs, 1995):

- generating (creating) information,
- gathering (gathering) information,
- storing (remembering, warehousing, archiving) information,
- transfer (transmission) of information,
- transforming (processing) information,
- interpretation (use, use) of information.

Typically, information systems perform several of these functions, and some perform all of the above functions. Their structure depends mainly on the purpose for which the information is to be served, as well as on the size and scope of the company's activities.

3. Marketing information system in enterprise

Information systems can be used in virtually all areas of a medical entity's business. The information system covers information processes of individual parts of the enterprise, which are separated due to the functions they perform. The variety of applications of information systems resulted in adaptation to the needs of a specific area of activity of a medical entity. Hence, we can distinguish information systems dedicated to specific areas of activity of an entity providing dental services. One of them is the marketing information system. Marketing activities are aimed at, among others: examining customer needs and satisfying them, while striving to achieve the best possible financial results of the medical entity (Bukowska, 2022). Marketing management is defined as the process of "planning and implementing ideas, shaping prices, promoting and distributing goods, services and ideas, aimed at leading to an exchange that meets the expectations of target groups of customers and organizations" (Kotler, 2012). In other words, decision-making problems arise in its sphere related to matching supply to demand (Andruszkiewicz, 2014). They include the processes of market research and shaping the market opportunities of medical entities, planning, shaping the forms of services and prices they offer, improving quality, creating exchange and satisfying the individual and collective needs of entities on the competitive medical services market.

The role of marketing in a company is to determine consumer preferences and satisfy their needs and ideas in such a way that the company makes a profit and the buyer is satisfied with the transaction (Mercer, 1992). In order to implement these tasks, the company must: select or define potential customers and the type of needs it wants to satisfy, conduct a detailed analysis of the preferences, desires and capabilities of buyers and the current degree of their satisfaction, taking into account the activities of competitors, plan an appropriate strategy for the composition of marketing instruments and implement appropriately shaped plans, organizational forms and using appropriate management and results control systems.

According to Ph. Kotler, marketing management is "the process of planning and implementing ideas, shaping prices, promoting and distributing goods, services and ideas, aimed at leading to an exchange that meets the expectations of customer groups and organizations" (Kotler, 2012).

Effective marketing management in an enterprise consists in proper programming of the structures of its individual elements, i.e. the structure of:

- services (quality, range of products, brand),
- prices (price list, discounts, commissions, additional costs),
- distribution (location, available patient registration channels, patient service),
- promotion (advertising, promotion, public relations),
- people,
- physical evidence,
- processes.

Today's marketing, however, uses a huge amount of information, not all of which is necessary and up-to-date. That is why their selection and skillful processing is so important, which is to be ensured by the introduction of a marketing information system (Ślusarczyk, 2020). The main goal of a marketing information system is to transform marketing data from various sources into information needed to make appropriate marketing decisions. The operation of this system is the result of learning about trends and directions of development of the environment (Ślusarczyk, 2020).

Information processed in the form of data must be properly structured and ordered, depending on the functions and tasks of the system, the nature of the decisions made and the structure of technological processes. In other words, they must create an appropriate structure, the basic components of which are information units and the relations between them, as well as procedures for their transformation (Mytlewski, 2007). Structuring helps in recognizing the structure of the problem, thus maximizing the amount of information that can be collected about a given problem. The less the structure of the problem is recognized, the more difficult it is to predict the system's behavior that would bring benefits (Majecka, 2003). Information is structured through information systems. The postulate of information structuring requires appropriate structuring of information systems. Structuring information systems is a process that determines the usefulness of information (Mytlewski, 2007).

Information structuring is intended to organize information (to isolate logical systems) so that it can be used by managers managing medical units. The structuring of the information system should be carried out by dividing the system into several interacting (interrelated) basic subsystems/components, each of which solves certain partial tasks, which will allow the adaptation of given subsystems/components to the requirements (needs) of their users, so as to provide them access to any cross-section of information that will help them find the most optimized solution (Combs, 1995).

Structuring the information systems of a medical entity ensures:

- access to high-quality information,
- providing information about changes and symptoms of changes as quickly as possible (the structure must include components that will allow controlling the environment and adapting to it), which is to ensure appropriate adaptation of the enterprise to the environment,
- completeness of the collection in relation to the user's needs (the supply of information coincides with the demand),
- reducing the time needed to make a decision to a minimum (thanks to shortening the time needed to complete and collate information, which allows you to focus on proper assessment and analysis),
- ability to fully integrate all spheres of the company's activity; merging the organization's components into one (integral) whole,

- common data set for different users,
- internal order in the organizational system, because the structure performs important regulatory functions,
- standardization of rules of conduct,
- relative balance of the system,
- reducing uncertainty in operation,
- possibility of testing the entire system.

Every company, including dental offices, uses sets of various information. They can be organized by using various types of classifications. Thus, using the place of creation of marketing information as a criterion, we can distinguish (Unold, 2009):

- internal information available in the company that produces it: the company's sales volume in terms of services and buyers (depending on what elements are needed in the decision-making process), level and structure of costs across services and buyers, enterprise potential.
- external information, available only within the environment of the company that uses it, i.e.: competitors' sales volume, size and cost structure of competitors, capacity of various segments, buyers' behavior on the market (including data on their patterns of behavior on the market, e.g. loyalty to the trademark, reaction to advertising and other means of marketing influence of the company, behavior before purchases, characteristics of behavior when purchasing), level and structure of buyers' income, market structure and degree of competitiveness, market entry conditions, conditions of the legal environment (competition regulation, legal aspects of decisions), conditions of the political environment (e.g. political stability of the country),
- information obtained from both sources: market share, share in the costs of servicing a given market, market position of the company, trust in the trademark.

Effective management of the marketing area would be impossible without a marketing information system (SIM) (Frąckiewicz, 2004). The basic feature of a marketing information system should be its usefulness for making marketing decisions. In addition to the basic function of providing marketing information, SIM should ensure an uninterrupted flow of information to all other field information systems and the management information system. This system cannot be isolated and work in isolation from other areas of the company's operation (Andruszkiewicz, 2014) Market decisions of managers of medical entities concern two main groups of variables:

- controlled variables that depend on the decision-maker, including primarily the company's tools for influencing the market,
- uncontrolled variables, including:

- variables that are not subject to the influence of marketing instruments (e.g. macroeconomic indicators of the country, average level of earnings in the region),
- variables that are, to some extent, susceptible to the impact of these instruments (e.g. market behavior of buyers, competition situation).

External marketing information plays a special role in making marketing decisions in an organization (Unold, 2009). Since the basic task of SIM is to "estimate information needs, process appropriate data and provide them at the right time to marketers", according to this concept, the SIM structure can distinguish interrelated groups of the following subsystems (Unold, 2009):

- information collection subsystem, which consists of:
  - operational information subsystem/internal company archives,
  - marketing "intelligence" subsystem,
  - marketing research subsystem,
- decision support subsystem.

The operational information subsystem aims to constantly collect information regarding current phenomena taking place in the enterprise. This system does not analyze the causes of specific phenomena, it only registers them, thus obtaining premises for making routine decisions relating to repeatable phenomena. Data is collected continuously, in the form of periodic reports, which include, among others: information on the volume of services provided, sales, prices, receivables, payments, liabilities, costs in various sections. This subsystem is usually based on electronic data processing. The marketing intelligence subsystem aims to obtain daily information regarding the development of the situation in the company's environment. This system collects information by reading books, magazines, attending trade fairs, and talking to customers, suppliers and intermediaries. The marketing research subsystem collects information for the purpose of solving specific problems occurring in medical units. It mainly provides data for making strategic and tactical decisions, as well as allows identifying the causes of changes in the levels of phenomena registered in the operational information subsystem. Marketing research includes, for example, advertising research (research on media, measurement of advertising effectiveness), economic research (short- and long-term forecasts, research on market trends, research on prices), product research (analysis of the strengths and weaknesses of own services and those of competitors, acceptance new product, research on competitors' products, testing existing products), market research (measurement of market potential, market share of main competitors, identification of market characteristics, structure and organization of distribution channels, economic factors and other factors affecting the dental services market), research sales (e.g. sales analysis, market tests) (Frąckiewicz, 2004). An enterprise providing medical services operating in accordance with the marketing concept satisfies buyers of its services, thus having a chance to achieve a competitive position and market success (Andruszkiewicz, 2014).

4. Marketing information system in dental entity

In today's socio-economic realities, the medical services market, including the dental services market, where an increasing amount of revenues generated by this market is covered by the private sector, has become a highly competitive market (www.pmrmarketexperts.com). The increase in the competitiveness of the dental market results not only from the existence of an increasing number of private facilities, but also from the increase in patient awareness and changing expectations regarding the quality and availability of health services (Nadzkiewicz, 2018). Please remember that medical services are of a special nature. It is related to their subject (health, human life), as well as the role played by medical staff who decide about the patient's health. The specialist medical knowledge of a dentist is the basis for working with a patient, and the medical procedures he uses are the most important factors influencing the quality of health services (Majewski, 2022) Managing a dental office requires constant analysis of the environment and resources, attention to ensuring high quality health services and constant competition for the patient.

A dental office cannot create new quality without knowing the environment, recognizing its realities and trends, and quickly reacting to changes taking place there. The company does not operate for itself, but is included in the market, it must collect all kinds of information from it and process it appropriately and use it in the marketing management process to meet market needs, otherwise its competitive position will be threatened (Żurek, 2016). Appropriate organization of information also has an unquestionable impact on its ability to be used. Conducting marketing activities requires numerous analyzes of patient behavior, the effectiveness of promotional activities, the price level of medical services, competition, and the entire market. In order to implement these activities, however, reliable information is necessary - its collection, processing and transfer to managers who are able to use it to make not only marketing decisions, but also strategic ones from the point of view of the entire enterprise (Nowicki, 2005).

Entities providing dental services should therefore structure their marketing information system in such a way as to collect information needed to make marketing decisions:

1. from the external environment:
    1.1. macroeconomic:
        - regarding identified and programmed development trends of the sector and the economy (average income, general economic growth, inflation, interest rates and unemployment);
        - socio-cultural including information on customs, habits, values and demographic features of the society in which the medical entity operates. They are important because they determine what services society will value the most;

- political and legal (tax policy, legal regulations (e.g. consumer protection law, medical regulations, GDPR), impact of the political situation on a given industry,

1.2. about the dental market:

- the condition of the dental sector,
- changes in regulations and other formal and legal conditions for the operation of dental entities,
- market size and characteristics by gender, age and income,
- market shares of main competitors,
- competitor prices,
- types of services, new services,
- types of marketing activities offered,
- shopping trends, behaviors and needs of individual consumer groups,
- quality of services provided or desired service qualities,
- progress in medical technologies and techniques,
- price analysis,
- analysis of competitors, cooperators and intermediaries,

2. Coming from the internal environment

2.1. Information collected before performing a dental service (registered/collected on an ongoing basis):

- form of registration (by phone, e-mail, communicator such as Messenger, portal such as Znany Lekarz, Kliniki.pl, contact form available on the website, widget, in person);
- if the patient is a first-time patient, information from where he found out about the clinic (Internet, blog, from friends/family, passed by the office, social media, advertising such as a banner, leaflet, etc. etc.);
- what made the patient choose a given dental office (specific specialist, staff and quality of his education, price, positive opinions on Google, positive opinions of friends/family, referral from another doctor, location, wide range of services, wide range of services, equipment, medical equipment, e.g. availability of equipment, i.e. 3D tomograph, materials used, short waiting time, promotional activities, etc.);

2.2. Information collected after performing a dental service (registered/collected on an ongoing basis):

- information about clients/patients (number, age, gender, place of residence);
- quantitative and value structure of the services provided;
- value of revenues by doctors, by offices, and by type of service.

2.3. Information from assessments and analyzes performed most often once a month/week (Rzeźnicki, 2018; Rogala, 2014; Ostrowska):
- dynamics and structure of sales revenues (total, according to criteria, e.g. doctor, office, type of service);
- dynamics and cost structure of marketing activities;
- marketing costs per 1 new patient, share of marketing costs in generic costs and revenues, etc.;
- profitability of individual services, offices/chairs, doctors;
- assessment of the effectiveness of marketing activities (number of new patients, conversion rates, patient loyalty (number of regular/returning patients), effectiveness of discount/promotional campaigns, assessment SEO positioning, Google Ads sponsored links, etc. etc.;
- cost/effect analysis;
- number of first-time patients continuing treatment;
- the number of consultations/quotes performed and the number of dental services performed;
- the number of positive and negative opinions online, the number of complaints submitted;
- website evaluation; conversion rate - number of visits to the website, time spent on the website, number of returns to the website, number of clicks on the advertising banner provided on the website, number of clicks on the video on the website, navigating to subpages within the website, sharing further by the customer, e.g. article or product on social media;
- comparative analysis of service prices;
- number of new patients from individual marketing campaigns;
- assessment of patient preferences;
- short and long-term forecasts based on trend analysis;
- price and profit analysis;
- evaluation of the registration work (total number of calls, number of missed calls, number of patients registered for a medical visit, surveying the market, especially those undecided to make an appointment).

Nowadays, information collected in medical entities plays a key role in improving the quality of medical services provided. Such a structured marketing information system will support the dental office management staff in terms of supporting the process of research and development of dental services, supporting the process of creating and analyzing patients' needs, identifying opportunities to introduce new services, constantly collecting and storing marketing information, filtering and processing information, implementing communication procedures, providing premises for setting competitive prices, preparing promotional

campaigns, controlling the costs of marketing activities, providing data for analyzing the effectiveness of marketing activities, providing information for the process of preparing a long-term corporate strategy and supporting the process of selecting specific strategic goals and subordinated service strategies, prices and promotion (Unold, 2009).

References

1. Andruszkiewicz, K., Schulz M. (2014). System informacji marketingowej w procesie budowania trwałych relacji z klientem na przykładzie polskich przedsiębiorstw. *Marketing i Rynek, 11*.
2. Bukowska-Piestrzyńska, A. (2022). *Marketing usług zdrowotnych - od budowania wizerunku placówki do zadowolenia klienta*. Warszawa: CeDEWU.
3. Combs, M.R. (1995). *Information Systems for Business Management*. London: Pitman Publishing.
4. Dołhasz, M., Fudalińska, J., Kosala, M., Smutek, H. (2009). *Podstawy zarządzania. Koncepcje-strategie-zastosowania*. Warszawa: PWN.
5. Frąckiewicz, E., Karwowski, J., Karwowski, M., Rudawska, E. (2004). *Zarządzanie marketingowe*. Warszawa: PWE.
6. Kotler, Ph. (2012). *Marketing*. Poznań: Rebis.
7. Majecka, B. (2003). *Zachowania organizacyjne przedsiębiorstw*. Gdańsk: Wydawnictwo Uniwersytetu Gdańskiego.
8. Majewski, A., Merkisz-Gurantowska, A., Czarnota, K. (2022). Metoda oceny efektywności zarządzania gabinetem stomatologicznym. *Zeszyty Naukowe Politechniki Poznańskiej, Organizacja i Zarządzanie*, *no. 86*, pp. 101-122.
9. Mercer, D. (1992). *Marketing*. Oxford: Blackwell.
10. Mytlewski, A. (2007). *Monitoring ekonomiczny przedsiębiorstw*. Gdansk: Wydawnictwo Uniwersytetu Gdańskiego.
11. Nadzkiewicz, M. (2018). Marketing a jakość usług medycznych na przykładzie placówki region Górnego Śląska. *Zeszyty Naukowe Politechniki Śląskie seria Organizacja i Zarządzanie, z. 129*, pp. 313-324.
12. Nowak, E. (2014). *Proces zarządzania ryzykiem a system informacyjny przedsiębiorstwa*. Wrocław: Wydawnictwo Uniwersytetu Ekonomicznego we Wrocławiu.
13. Nowicki, A., Chomiak-Orsy, I. (2007). *Systemy informacyjne logistyki. Modelowanie*. Wrocław: Wydawnictwo Akademii Ekonomicznej im. O. Langego we Wrocławiu.
14. Ostrowska, S. *Kształtowanie wizerunku podmiotu działalności leczniczej*. Retrieved from: https://www.ue.katowice.pl/fileadmin/_migrated/content_uploads/11_S.Ostrowska_Kształtowanie _wizerunku_podmiotu.pdf, 11.07.2024.

15. Rogala, M., Badora-Musiał, K., Kowalska, I., Mokrzycka, A. (2014). Rola działań marketingowych w zarządzaniu podmiotem leczniczym na przykładzie Uniwersyteckiego Szpitala Dziecięcego w Krakowie. *Zdrowie Publiczne i Zarzadzanie, vol. 12, no. 2*, pp. 163-174.
16. *Rynek stomatologiczny z uśmiechem patrzy w przyszłość*. Retrieved from: https://www.pmrmarketexperts.com/wiadomosci/rynek-stomatologiczny-z-usmiechem-patrzy-w-przyszlosc/, 10.07.2024.
17. Rzeźnicki, A., Kunert, A., Stefanek, J., Krakowiak, J. (2018). Determinanty wyboru gabinetu stomatologicznego na przykładzie wybranego gabinetu stomatologicznego w Łodzi. *Przedsiębiorczość i Zarządzanie, t. 19, z. 12, cz. 1*, pp. 59-73.
18. Szałucki, K. (2017). Racjonalność finansowa jako czynnik podejmowania decyzji rezultatowych w przedsiębiorstwie. In: J. Krupska, K. Szałucki (Eds.), *Efektywność finansowa przedsiębiorstw w perspektywie podstawowych zagadnień teorii i praktyki diagnozowania ekonomicznego i funkcjonowania przedsiębiorstw: publikacja dedykowana pamięci Profesora Mirosława Krajewskiego*. Gdańsk: Wydawnictwo Uniwersytetu Gdańskiego.
19. Ślusarczyk, S. (2020). Use of the Marketing Information System in the enterprise as a basis for efficient management (on the example of the SME sector in the Subcarpathian Voivodeship). *Zeszyty Naukowe Małopolskiej Wyższej Szkoły Ekonomicznej w Tarnowie, 2(46)*, pp. 133-145.
20. Unold, J. (2009). *Systemy informacyjne marketingu*. Wrocław: Wydawnictwo Uniwersytetu Ekonomicznego we Wrocławiu.
21. Wachowiak, P. (2006). *Funkcjonowanie przedsiębiorstwa w gospodarce rynkowej*. Warszawa: Stowarzyszenie Księgowych w Polsce.
22. Żurek, J. (2016) *Przedsiębiorstwo. Drogi sukcesu rynkowego*. Warszawa: PWE.

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ADVANCING GENDER DIVERSITY: THE ROLE AND IMPACT OF WOMEN IN ENGINEERING

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Purpose: This article explores the role and impact of women in engineering, highlighting how increasing gender diversity can drive innovation and contribute to the overall success of the engineering sector. The participation of women in engineering not only addresses workforce gaps but also fosters inclusive work environments that encourage diverse perspectives in problem-solving and product development.
Design/methodology/approach: A comprehensive literature review and analysis of industry reports were conducted to examine the structural and social factors influencing gender diversity in engineering.
Findings: The study reveals that while progress has been made in promoting gender diversity, women remain underrepresented in engineering roles. However, their contributions lead to improved team dynamics, innovative solutions, and stronger organizational performance. Additionally, the presence of women in leadership positions enhances organizational culture and encourages mentorship and support for future female engineers.
Research limitations/implications: Efforts to advance gender diversity in engineering must address challenges such as gender bias, workplace culture, and career development opportunities. Ensuring a supportive and inclusive environment is essential for retaining and advancing women in engineering roles.
Practical implications: The paper highlights strategies for organizations to foster gender diversity, including targeted recruitment efforts, mentorship programs, and creating a culture that values diversity.
Originality/value: This article provides actionable insights and strategic guidance for engineering firms aiming to enhance gender diversity and benefit from the unique contributions women bring to the field. It is especially valuable for companies seeking to improve innovation and inclusivity through diverse workforces.
Keywords: Gender Diversity, Women in Engineering, Innovation, Workforce Inclusion.
Category of the paper: This article reviews the factors affecting gender diversity in engineering and explores the benefits and challenges of fostering an inclusive workforce.

1. Introduction

Engineering, a field traditionally dominated by men, has undergone significant transformation in recent decades, with an increasing emphasis on gender diversity and inclusion. The growing recognition of the underrepresentation of women in engineering has prompted numerous studies and initiatives aimed at fostering diversity, not only to address equity concerns but also to enhance the performance, creativity, and innovation capacity of engineering teams (Avolio, 2020). The benefits of gender diversity in the workplace are well documented; diverse teams are more likely to offer a wider range of perspectives, leading to more robust problem-solving and innovative solutions. In engineering, where complex, interdisciplinary challenges are the norm, the inclusion of women can play a critical role in broadening the scope of design and technological advancements (Casad, 2021). Despite this progress, the underrepresentation of women in engineering remains a persistent global issue. According to UNESCO (2021), women constitute only 28% of the global engineering workforce, with notable regional disparities. In countries with more progressive gender policies, such as those in Western Europe, women's representation is somewhat higher, yet still below parity, while in regions like the Middle East and South Asia, women's participation in engineering is particularly low. This gender gap can be traced to a variety of socio-cultural, educational, and institutional factors, including gender stereotypes, lack of female role models, and systemic biases in both academic and professional settings (Verdugo-Castro, 2022). The literature on this topic has increasingly focused on addressing these barriers and identifying strategies to support and retain women in engineering careers (Makarem, 2020).

Historically, gender stereotypes have significantly influenced the perception of engineering as a "male" profession (Tabassum, 2021). Engineering has been associated with traits traditionally viewed as masculine, such as technical proficiency, problem-solving, and hands-on work. This perception has discouraged many women from pursuing engineering as a viable career path, despite their equal capability in these areas. Research by Cheryan et al. (2017) suggests that societal stereotypes about gender and technical ability begin in childhood and are reinforced throughout education, contributing to the lower enrollment of women in engineering programs at universities. These gendered perceptions not only affect young women's choices but also create environments within engineering education and workplaces that may feel unwelcoming or even hostile to female engineers (O'Connell, 2021).

Education, therefore, plays a crucial role in both perpetuating and challenging these gender disparities (Kuchynka, 2022). Numerous studies point to the importance of early exposure to STEM (Science, Technology, Engineering, and Mathematics) subjects as a way to mitigate the impact of gender stereotypes. Interventions such as mentorship programs, gender-sensitive curricula, and outreach initiatives that specifically target girls and young women have shown promise in increasing female participation in engineering (Kuteesa, 2024). For instance,

programs that introduce girls to engineering concepts through hands-on, practical experiences, such as robotics clubs or coding workshops, have been found to increase interest and confidence in engineering fields (Master, Cheryan, Meltzoff, 2016). Furthermore, female role models in engineering play a crucial role in shaping the aspirations of young women. Studies have demonstrated that when women see others like themselves succeeding in the field, they are more likely to envisage engineering as a potential career path (O'Connell, 2021).

The workplace culture within engineering organizations also poses significant challenges for women (O'Connor, 2020). Women engineers often report feeling isolated or excluded in male-dominated environments, and gender biases in recruitment, promotion, and salary negotiation persist. Studies by Fouad and Singh (2011) indicate that women are more likely than their male counterparts to leave engineering careers, citing reasons such as lack of advancement opportunities, hostile work environments, and work-life balance difficulties. This phenomenon, often referred to as the "leaky pipeline", highlights the need for structural reforms within engineering companies and institutions to retain women and foster inclusive work environments (Gregor, 2023). Initiatives such as flexible work policies, unconscious bias training, and diversity and inclusion programs are becoming increasingly prevalent in addressing these issues. Moreover, advocacy for more female leadership in engineering is gaining momentum, as research consistently shows that women in leadership positions can drive cultural change and serve as role models for the next generation of female engineers (Holtzblatt, 2021).

2. Literature Review

Diversity and inclusion in the workplace have become critical areas of focus across multiple sectors, particularly in industries that thrive on innovation, such as engineering, technology, and manufacturing (Snowball, 2022). Research increasingly demonstrates that diverse teams are better positioned to approach problems with creativity, adaptability, and a broader range of perspectives, ultimately leading to more innovative solutions (Hundschell, 2022). Gender diversity, in particular, has been shown to positively impact organizational performance, enhancing profitability, productivity, and overall team dynamics (Martinez-Jimenez, 2020). This literature review explores key studies and reports on diversity, innovation, and workforce inclusion, emphasizing the need for greater gender diversity in engineering and related fields.

One of the most significant contributions of diversity to innovation is the way in which it fosters a variety of perspectives. Homogeneous teams, while often more comfortable in terms of collaboration, tend to approach problems from similar viewpoints, which can limit creativity. Homan et al. (2020) emphasize that gender-diverse teams are more likely to challenge conventional thinking and offer unique solutions, which is particularly important in sectors like

engineering that deal with complex, interdisciplinary challenges. This creative problem-solving is further enhanced when diverse teams are placed in inclusive environments that encourage open communication and the free exchange of ideas (Leroy, 2022). Numerous studies have highlighted the economic benefits of gender diversity, particularly in leadership roles. The World Economic Forum (2022) reports that companies with higher gender diversity in leadership outperform those with less diversity in terms of profitability and productivity. These companies are better able to navigate volatile markets, adapt to changing demands, and implement innovative strategies (Wilk, 2020). Gender diversity in leadership also sets a tone for the broader organizational culture, promoting inclusion and encouraging a more diverse talent pool to rise within the ranks (Makarem, 2024). Despite the clear advantages of gender diversity, women remain significantly underrepresented in engineering, one of the most innovation-dependent fields. UNESCO (2023) found that women account for only 28% of the global engineering workforce. Moreover, fewer women pursue advanced degrees in engineering, and those who do are less likely to occupy leadership roles compared to men (Ross, 2022). This discrepancy is often attributed to a variety of factors, including deep-seated gender biases and stereotypes that suggest women are less suited for STEM (Science, Technology, Engineering, and Mathematics) careers. These biases not only affect hiring and promotion practices but also contribute to a lack of visible female role models in the field (Tandrayen, 2022). Cultural and structural barriers continue to impede the advancement of women in engineering (Swafford, 2020). Gender biases in hiring, promotion, and performance evaluations are well-documented, with many women reporting that they feel undervalued or overlooked for key opportunities (Kong, 2020). These biases are often unconscious but deeply ingrained, reflecting broader societal norms that associate technical and leadership capabilities with masculinity. In addition to these biases, workplace cultures in engineering are often described as unwelcoming or even hostile to women, contributing to higher turnover rates among female engineers (Gonzalez-Perez, 2022). Addressing these barriers requires systemic changes at multiple levels. Educational institutions, for example, play a crucial role in shaping perceptions of engineering as a viable career path for women (Makarem, 2020). Early exposure to STEM education, gender-inclusive curricula, and targeted outreach programs can help encourage more girls and young women to pursue engineering. Mentorship programs that connect female students with professional engineers have also been shown to boost confidence and interest in engineering careers (Guenaga, 2022). Furthermore, companies must adopt more inclusive hiring and promotion practices, invest in unconscious bias training, and create environments where diverse talent can thrive (Woods, 2021). Workplace inclusion is another key factor in retaining women in engineering. Inclusive environments are those where all employees feel valued, heard, and empowered to contribute their ideas (Shore, 2022). In such settings, diverse teams are not only more likely to innovate but also more likely to succeed in implementing their ideas. This is especially important in engineering, where collaboration across disciplines is often essential to solving complex problems. Inclusion initiatives such as flexible work policies,

diversity and inclusion training, and the promotion of female leadership can help address many of the challenges women face in the workplace. As Homan et al. (2020) point out, the success of diverse teams hinges on the extent to which organizations create inclusive environments that support collaboration and open dialogue. The global demand for engineers is rising rapidly, driven by technological advancements and societal challenges such as climate change. Engineering is crucial to addressing these challenges, but the shortage of skilled engineers, combined with the underrepresentation of women in the field, presents a significant obstacle (Lekchiri, 2020). By improving gender diversity, companies can tap into a wider talent pool, bridge the skills gap, and foster the innovation necessary to meet future workforce needs. Encouraging more women to enter and remain in engineering is not only a matter of equity but also a practical strategy for driving innovation and ensuring long-term competitiveness in the global market (Ventura, 2021). In conclusion, the literature on diversity, innovation, and workforce inclusion clearly demonstrates the significant advantages of gender diversity in engineering and other innovation-dependent fields. While progress has been made, substantial barriers to the advancement of women in engineering persist, including gender biases, stereotypes, and exclusionary workplace cultures (Schmader, 2023). Addressing these challenges requires a comprehensive approach involving educational reform, corporate responsibility, and societal change. Only through continued efforts to create more inclusive and diverse environments can the full potential of gender diversity be realized, ultimately driving greater innovation and success in engineering and beyond (Helman, 2020). Additionally, workplace culture in many engineering firms is often described as being male-centric, which can contribute to feelings of isolation among women engineers (Smith, 2020). This culture is often perpetuated by the lack of diversity in leadership positions, where women are vastly underrepresented. According to the Society of Women Engineers (2023), women hold less than 15% of managerial positions in engineering firms globally. Another significant barrier is the work-life balance challenge, which disproportionately affects women, especially those with caregiving responsibilities. Engineering, like many other technical professions, is often associated with long hours and demanding project schedules, which can discourage women from entering or staying in the profession (Rosa, 2022). The "leaky pipeline" phenomenon, where women exit the field at various career stages, is particularly pronounced in engineering (Park, 2023). Women in engineering are more likely than their male counterparts to leave the profession mid-career due to a lack of support for work-life balance, limited opportunities for advancement, and hostile work environments. In recent years, there has been a concerted effort from both academic institutions and industry to address these challenges and promote gender diversity in engineering (Casad, 2021). Many engineering schools have implemented programs aimed at increasing the enrollment and retention of women in STEM disciplines. For instance, universities are creating mentorship programs that connect female students with successful women engineers, providing them with role models and support networks to help them navigate

their academic and professional journeys (Gartstein, 2021). Industry reports from leading engineering firms also indicate a growing commitment to diversity and inclusion initiatives.

The advancement of women in engineering is not only a matter of equity but also a strategic imperative for the industry (Bonet, 2020). Increasing gender diversity can drive innovation, enhance team performance, and help address the growing demand for skilled engineers. While progress has been made in recent years, significant barriers remain, particularly in terms of workplace culture, career advancement opportunities, and work-life balance (Rashmi, 2022).

3. Methodology

This study employs a literature review approach and analysis of industry reports. According to Paul and Criado (2020), there are three types of reviews: domain-based, theory-based, and method-based. The approach taken here aligns with the domain-based review, which synthesizes and expands upon literature within a specific field or topic (Palmatier et al., 2018). The data for this review comes from various sources, including company reports, news articles, and institutional databases. Notably, there are no strict methodological limitations on how the data is analyzed. This research focuses of companies such as: Siemens, General Electric, Lockheed Martin, and BAE Systems. Companies like Siemens, General Electric, and Lockheed Martin, which have launched diversity programs that include gender diversity targets, unconscious bias training for managers, and flexible work policies designed to improve work-life balance (Engineering UK, 2023). These programs are aimed at not only recruiting more women into engineering roles but also creating a supportive environment where they can thrive and advance in their careers. Despite these initiatives, progress remains slow, and many challenges persist. A 2023 report by McKinsey & Company notes that while many organizations have made public commitments to diversity, the actual representation of women in technical and leadership roles has seen only modest increases. The report highlights the need for more comprehensive and sustained efforts, including policy changes, to address the root causes of gender inequality in engineering.

Siemens (www. siemens.com) is a global technology powerhouse founded in 1847, in Berlin, Germany, by Werner von Siemens. Initially focused on telegraph technology, Siemens has since expanded into a wide range of industries, including energy, automation, healthcare, and transportation. The company is known for its innovation in electrification, automation, and digitalization, providing advanced solutions in industrial manufacturing and infrastructure. Siemens has a strong commitment to sustainability and diversity, with a major focus on digital transformation across its operations.

General Electric (GE) was founded in 1892 by Thomas Edison and Charles Coffin, combining Edison's various businesses into a corporation. Headquartered in Boston, Massachusetts, GE has been a leader in industries such as energy, aviation, healthcare, and power systems (www.ge.com). The company has played a key role in shaping modern technologies, from early electrical innovations to advanced jet engines and medical imaging equipment. GE is known for its commitment to innovation and corporate sustainability, as well as fostering diversity in technical roles.

Lockheed Martin (www.lockheedmartin.com) is an American aerospace, defence, and security company formed in 1995 from the merger of Lockheed Corporation and Martin Marietta. Headquartered in Bethesda, Maryland, Lockheed Martin is one of the largest defence contractors in the world, specializing in the development and production of advanced technology systems, including military aircraft, missiles, and space exploration technologies. The company plays a key role in U.S. defence and aerospace innovation, supporting a wide range of government and civilian projects.

BAE Systems, founded in 1999, is a British multinational defence, aerospace, and security company based in London. It was formed through the merger of British Aerospace and Marconi Electronic Systems. BAE Systems is a leading global defence contractor, known for its work in military aircraft, naval vessels, submarines, and advanced electronics systems. The company serves governments' commercial customers worldwide, playing a crucial role in defence innovation and security technologies. BAE Systems is also actively working on gender diversity and sustainability initiatives across its workforce (www.baesystems.com).

4. Findings

Siemens has demonstrated a strong commitment to improving gender diversity, particularly within its engineering divisions. According to Siemens' 2023 Annual Diversity and Inclusion Report (www.siemens.com), the company has set ambitious targets to increase the representation of women in leadership positions. Siemens aims to have women occupy 30% of its leadership roles by 2025, a significant step towards achieving gender parity at the highest levels of the organization. To support this goal, Siemens has implemented targeted recruitment and mentorship programs specifically designed for women in STEM fields. These programs are intended to attract, retain, and promote female talent within the company. For example, Siemens has established initiatives that focus on identifying and nurturing women with high potential in engineering and other technical roles. By providing tailored mentorship and professional development opportunities, Siemens seeks to address the systemic barriers that have historically hindered women's advancement in engineering. Moreover, Siemens actively promotes

an inclusive culture through its Siemens Diversity Charter. This charter is a comprehensive framework aimed at ensuring equal opportunities for all employees, regardless of gender, background, or identity. It outlines the company's commitment to fostering a workplace where diversity is valued and where all employees feel included and supported. The charter serves as a guiding document for Siemens' diversity and inclusion strategies, ensuring that efforts to promote gender equality are embedded in the company's corporate culture and practices. Siemens' flexible working policies also play a crucial role in supporting gender diversity. The company offers remote work options and family-friendly hours, which are particularly beneficial for women balancing career and caregiving responsibilities. These policies are designed to create a more accommodating work environment, helping employees manage their professional and personal lives more effectively. The positive impact of these policies has been recognized by independent organizations, with Siemens being listed among the top companies for gender equality in engineering by Forbes in 2023. This recognition underscores the effectiveness of Siemens' strategies in promoting a more inclusive and supportive workplace.

General Electric's Balance the Equation initiative (www.ge.com), launched in 2021, represents a significant commitment to increasing the number of women in technical roles across the company. GE has set ambitious goals, including a target of having 20,000 women in STEM roles by 2030 and achieving gender parity in engineering positions by 2050. These targets reflect GE's recognition of the critical role that gender diversity plays in driving innovation and maintaining a competitive edge in the industry. To support these goals, GE has developed a range of internal programs focused on attracting and developing female talent. One such program is the Women's Network, an internal platform designed to connect female employees with mentors and sponsors who can provide guidance and support throughout their careers. This network facilitates professional development and helps women navigate the challenges associated with advancing in technical fields. GE's commitment to diversity is also reflected in its recruiting policies, which prioritize hiring from a diverse talent pool. The company partners with universities and organizations such as the Society of Women Engineers (SWE) to encourage more women to pursue STEM education and careers. These partnerships help create a pipeline of female talent and support the development of the next generation of engineers. The effectiveness of GE's diversity initiatives is evident in its 2022 diversity report, which shows a 5% increase in female technical hires compared to the previous year. This increase highlights the success of GE's efforts to attract and retain women in engineering roles. By focusing on both recruitment and development, GE is making significant strides towards achieving its diversity goals and ensuring that women have equal opportunities to succeed in technical careers.

Lockheed Martin (www.lockheedmartin.com) is another leading company making notable progress in gender diversity within its engineering divisions. The company has set a target of achieving 25% female representation in engineering roles by 2030. To reach this goal, Lockheed Martin has implemented a variety of programs and initiatives aimed at supporting

women in engineering. One of Lockheed Martin's key initiatives is the Women in Engineering program, which provides development opportunities through leadership training, mentorship, and networking events. This program is designed to help women advance in their careers and overcome the barriers that have historically limited their progress in engineering. By offering targeted support and professional development, Lockheed Martin aims to increase the number of women in senior engineering positions. Lockheed Martin also actively partners with educational institutions to support young women pursuing engineering degrees. The company's STEM Scholarship Program, launched in 2018, provides financial support to students from underrepresented backgrounds, including women, who are studying in STEM fields. This program helps alleviate the financial burden associated with higher education and encourages more women to pursue engineering careers. The Lockheed Women's Impact Network, an internal resource group, promotes dialogue and career advancement opportunities for female employees. This network fosters an inclusive and supportive workplace environment, where women can connect with peers, mentors, and leaders to advance their careers. Additionally, Lockheed Martin's Inclusion Pledge focuses on addressing gender bias within the workplace. This pledge includes regular training for managers on unconscious bias and revising policies to ensure equal opportunities in hiring and promotions.

BAE Systems (www.baesystems.com) is committed to increasing the representation of women in technical roles, with a goal of achieving a 50% increase by 2030. The company's diversity strategy is built around three key pillars: attracting more women to STEM, retaining female engineers by fostering an inclusive work environment, and providing development opportunities for women at all levels. One of BAE's notable initiatives is the Returners Program, which supports women who have taken career breaks and wish to return to the engineering profession. This program provides tailored training and flexible working arrangements to ease the transition back into the workforce. By addressing the unique challenges faced by women returning to work, BAE Systems helps facilitate their reintegration and supports their continued career development. Additionally, BAE's STEM Ambassadors initiative involves female engineers visiting schools to encourage young girls to consider engineering careers. This program aims to inspire the next generation of female engineers and address the gender gap at an early stage. By actively engaging with students and promoting engineering as a viable career path for women, BAE Systems helps build a more diverse talent pipeline for the future. BAE Systems tracks its progress through annual diversity reports, which show steady growth in the number of women in engineering roles. According to the company's 2023 diversity report, women now make up 18% of the engineering workforce, up from 14% in 2020. This increase reflects the effectiveness of BAE's diversity initiatives and its commitment to fostering a more inclusive engineering workforce.

5. Discussion

Women have significantly contributed to the engineering field, bringing diverse perspectives and skills that drive innovation. Research indicates that gender-diverse teams tend to outperform homogenous teams in problem-solving and creativity. For example, Homan (2021) highlight how teams with a higher percentage of women often demonstrate enhanced problem-solving abilities and more innovative solutions. This is attributed to diverse viewpoints that challenge conventional thinking and lead to more comprehensive and creative approaches to engineering problems. The inclusion of women in engineering not only promotes a more balanced representation but also contributes to better business outcomes. According to the World Economic Forum (2022), gender diversity in leadership roles correlates with improved financial performance and organizational effectiveness. Companies with diverse engineering teams are better positioned to address the needs of a broader customer base and to adapt to changing market demands.

Despite the positive impacts, women in engineering face several challenges that can hinder their career advancement. Stereotypes and biases remain prevalent, influencing hiring practices, promotion opportunities, and workplace culture. Tandrayen (2022) discusses how gender biases and societal stereotypes discourage women from pursuing engineering careers and contribute to the "leaky pipeline" phenomenon, where women drop out of engineering fields at higher rates than their male counterparts. Additionally, the lack of female role models and mentors in engineering can limit career progression for women. Park (2023) analyzes factors leading to career attrition among women in engineering, highlighting that inadequate support and mentorship are significant contributors. This lack of guidance can result in lower retention rates and fewer women advancing to senior technical and leadership positions. Work-life balance is another critical issue. Many women in engineering struggle to manage professional responsibilities alongside personal and family commitments. Policies that support flexible working arrangements and family leave are crucial but often insufficiently implemented. The challenges of balancing these demands can lead to higher attrition rates and lower overall job satisfaction among female engineers.

The ongoing efforts to improve gender diversity in engineering have several implications for the industry. Firstly, there is a growing recognition of the need for systemic change within organizations. Initiatives such as targeted recruitment, mentorship programs, and diversity training are essential to address the barriers faced by women in engineering. For example, companies like Siemens and General Electric have implemented comprehensive diversity programs aimed at increasing female representation in technical roles (Siemens Annual Diversity and Inclusion Report, 2023; General Electric, Balance the Equation Report, 2022). Moreover, there is an increasing emphasis on creating supportive and inclusive work environments. Organizations are investing in policies and practices that promote work-life

balance, such as flexible work hours and remote work options. These measures are crucial for retaining female engineers and ensuring their continued success and satisfaction within the industry.

While the existing literature provides valuable insights into the role and impact of women in engineering (Agurto, 2021), there are limitations that should be acknowledged. Many studies rely on self-reported data, which can introduce bias and affect the accuracy of the findings (Russo, 2020). Additionally, research often focuses on specific regions or sectors, which may not fully represent the global engineering landscape. There is also a need for longitudinal studies to track the long-term impacts of gender diversity initiatives. Short-term studies may not capture the sustained effects of diversity programs or the evolving challenges faced by women in engineering. Furthermore, while much research highlights the barriers and challenges, there is less focus on the effectiveness of various interventions and their real-world outcomes.

To address these limitations, future research should aim to include diverse and longitudinal data to provide a more comprehensive understanding of gender diversity in engineering. Studies should also explore the effectiveness of different diversity initiatives and policies, assessing their impact on both individual career outcomes and organizational performance. Additionally, there is a need for more research on intersectionality, examining how factors such as race, ethnicity, and socioeconomic background intersect with gender to affect experiences in engineering (Campbell-Montalvo, 2022). This will help create more nuanced and effective strategies for promoting diversity and inclusion in the field.

Advancing gender diversity in engineering is not only a matter of equity but also a strategic advantage for organizations. Women bring valuable perspectives and skills that enhance innovation and performance (Tahir, 2021). However, significant challenges remain, including biases, lack of mentorship, and work-life balance issues. Addressing these challenges requires systemic changes within organizations and continued research to develop and evaluate effective diversity initiatives. By overcoming these barriers and fostering an inclusive environment, the engineering industry can unlock its full potential and drive greater success and innovation (Opstad, 2024).

References

1. Agurto, M., Bazan, M., Hari, S., Sarangi, S. (2021). Women in engineering: The role of role models. *GLO Discussion Paper, No. 975*.
2. Avolio, B., Chávez, J., Vílchez-Román, C. (2020). Factors that contribute to the underrepresentation of women in science careers worldwide: *A literature review. Social Psychology of Education, 23(3)*, pp. 773-794.

3. BAE Systems. (2023). *Diversity and Inclusion Report*. Retrieved from: www.baesystems.com.
4. Bonet, R., Cappelli, P., Hamori, M. (2020). Gender differences in speed of advancement: An empirical examination of top executives in the Fortune 100 firms. *Strategic Management Journal, 41(4)*, pp. 708-737.
5. Campbell-Montalvo, R., Kersaint, G., Smith, C. A., Puccia, E., Skvoretz, J., Wao, H., Lee, R. (2022). How stereotypes and relationships influence women and underrepresented minority students' fit in engineering. *Journal of Research in Science Teaching, 59(4)*, pp. 656-692.
6. Casad, B.J., Franks, J.E., Garasky, C.E., Kittleman, M.M., Roesler, A.C., Hall, D.Y., Petzel, Z.W. (2021). Gender inequality in academia: Problems and solutions for women faculty in STEM. *Journal of Neuroscience Research, 99(1)*, pp. 13-23.
7. Engineering UK (2023). *Engineering Workforce Diversity Report*. Retrieved from: https://www.engineeringuk.com/research-policy/diversity-in-engineering/diversity-in-engineering/
8. Gartstein, M.A., Hancock, G.R. (2021). Professional development programs for women in academic science, technology, engineering, and math (STEM) fields: Enhancing retention and promotion. *International Journal of Gender, Science and Technology, 13(1)*, pp. 43-63.
9. General Electric (2022). *Balance the Equation Report*. Retrieved from: www.ge.com.
10. González-Pérez, S., Martínez-Martínez, M., Rey-Paredes, V., Cifre, E. (2022). I am done with this! Women dropping out of engineering majors. *Frontiers in Psychology, 13,* 918439.
11. Gregor, M., Dunn, M., Campbell-Halfaker, D., Martin-Fernandez, J., Ferrer, A., Robinson, S. (2023). Plugging the leaky pipeline: A qualitative investigation of untenured female faculty in STEM. *Journal of Career Development, 50(2)*, pp. 425-444.
12. Guenaga, M., Eguíluz, A., Garaizar, P., Mimenza, A. (2022). The impact of female role models leading a group mentoring program to promote STEM vocations among young girls. *Sustainability, 14(3)*, *1420*.
13. Helman, A., Bear, A., Colwell, R. (2020). (Eds.), *Promising practices for addressing the underrepresentation of women in science, engineering, and medicine: Opening doors*. Wahington: National Academies Press (US).
14. Holtzblatt, K., Marsden, N. (2022). *Retaining women in tech: Shifting the paradigm*. Springer.
15. Homan, A.C., Gündemir, S., Buengeler, C., van Kleef, G.A. (2020). Leading diversity: Towards a theory of functional leadership in diverse teams. *Journal of Applied Psychology, 105(10),* 1101.
16. Hundschell, A., Razinskas, S., Backmann, J., Hoegl, M. (2022). The effects of diversity on creativity: A literature review and synthesis. *Applied Psychology, 71(4)*, pp. 1598-1634.

17. Kong, S., Carroll, K., Lundberg, D., Omura, P., Lepe, B. (2020). Reducing gender bias in STEM. *MIT Science Policy Review, 1(8)*, pp. 55-63.
18. Kuchynka, S.L., Eaton, A., Rivera, L.M. (2022). Understanding and addressing gender-based inequities in STEM: Research synthesis and recommendations for US K-12 education. *Social Issues and Policy Review, 16(1)*, pp. 252-288.
19. Kuteesa, K.N., Akpuokwe, C.U., Udeh, C.A. (2024). Gender equity in education: Addressing challenges and promoting opportunities for social empowerment. *International Journal of Applied Research in Social Sciences, 6(4)*, pp. 631-641.
20. Leroy, H., Buengeler, C., Veestraeten, M., Shemla, M., Hoever, I.J. (2022). Fostering team creativity through team-focused inclusion: The role of leader harvesting the benefits of diversity and cultivating value-in-diversity beliefs. *Group & Organization Management, 47(4)*, pp. 798-839.
21. Lockheed Martin (2023). *Diversity and Inclusion Report*. Retrieved from: www.lockheedmartin.com.
22. Makarem, Y. (2024). Gender, Diversity, and HRD Strategies for Enhancing Women's Capabilities: A Global Perspective. In: *Feminism, Diversity and HRD* (pp. 78-99). Routledge.
23. Makarem, Y., Wang, J. (2020). Career experiences of women in science, technology, engineering, and mathematics fields: A systematic literature review. *Human Resource Development Quarterly, 31(1)*, pp. 91-111.
24. Martinez-Jimenez, R., Hernández-Ortiz, M.J., Cabrera Fernández, A.I. (2020). Gender diversity influence on board effectiveness and business performance. *Corporate Governance: The International Journal of Business in Society, 20(2)*, pp. 307-323.
25. McKinsey & Company. (2023). *Women in the Workplace: Engineering Sector Report.* Retrieved from: https://www.mckinsey.com/featured-insights/diversity-and-inclusion/women-in-the-workplace.
26. O'Connell, C., McKinnon, M. (2021). Perceptions of barriers to career progression for academic women in STEM. *Societies, 11(2)*, p. 27.
27. O'Connor, P. (2020). Why is it so difficult to reduce gender inequality in male-dominated higher educational organizations? A feminist institutional perspective. *Interdisciplinary Science Reviews, 45(2)*, pp. 207-228.
28. Opstad, L., Karevoll, G.G., Lewicka, D., Årethun, T. (2024). How gender and personality traits influence job preferences among students in Norway and Poland. *Cogent Business & Management, 11(1)*, *2354946*.
29. Palmatier, R.W., Houston, M.B., Hulland, J. (2018). Review articles: Purpose, process, and structure. *Journal of the Academy of Marketing Science, 46(1)*, pp. 1-5.
30. Park, M.H. (2023). *Mitigating the leaky pipeline: Women engineers' professional identity development as engineers in the field*. The Pennsylvania State University.

31. Paul, J., Criado, A.R. (2020). The art of writing literature review: What do we know and what do we need to know? *International Business Review, 29(4),* 101717.
32. Rashmi, K., Kataria, A. (2022). Work–life balance: A systematic literature review and bibliometric analysis. *International Journal of Sociology and Social Policy, 42(11/12)*, pp. 1028-1065.
33. Rose, R. (2022). The trouble with 'work–life balance'in neoliberal academia: A systematic and critical review. *Journal of Gender Studies, 31(1)*, pp. 55-73.
34. Russo, D., Stol, K.J. (2020). Gender differences in personality traits of software engineers. *IEEE Transactions on Software Engineering, 48(3)*, pp. 819-834.
35. Schmader, T. (2023). Gender inclusion and fit in STEM. *Annual Review of Psychology, 74(1)*, pp. 219-243.
36. Siemens (2023). *Annual Diversity and Inclusion Report*. Retrieved from: www.siemens.com.
37. Smith, N.E., Chowdhury, S., Costello, S.B. (2023). Examining the effectiveness of gender equity initiatives to support women in engineering. *Journal of Management in Engineering, 39(2),* 04022078.
38. Snowball, J., Tarentaal, D., Sapsed, J. (2022). Innovation and diversity in the digital cultural and creative industries. In: *Arts, entrepreneurship, and innovation* (pp. 187-215). Cham: Springer Nature Switzerland.
39. Society of Women Engineers (2023). *State of Women in Engineering Report*.
40. Swafford, M., Anderson, R. (2020). Addressing the Gender Gap: Women's Perceived Barriers to Pursuing STEM Careers. *Journal of Research in Technical Careers, 4(1)*, pp. 61-74.
41. Tabassum, N., Nayak, B.S. (2021). Gender stereotypes and their impact on women's career progressions from a managerial perspective. *IIM Kozhikode Society & Management Review, 10(2)*, pp. 192-208.
42. Tahir, S.H., Ullah, M.R., Ahmad, G., Syed, N., Qadir, A. (2021). Women in top management: Performance of firms and open innovation. *Journal of Open Innovation: Technology, Market, and Complexity, 7(1)*, p. 87.
43. Tandrayen-Ragoobur, V., Gokulsing, D. (2022). Gender gap in STEM education and career choices: What matters? *Journal of Applied Research in Higher Education, 14(3)*, pp. 1021-1040.
44. UNESCO (2023). *Cracking the Code: Girls' and Women's Education in STEM*. Retrieved from: https://unesdoc.unesco.org/ark:/48223/pf0000253479.
45. Ventura, A.M., Morillas, L., Martins-Loução, M.A., Cruz, C. (2021). Women's empowerment, research, and management: Their contribution to social sustainability. *Sustainability, 13(22),* 12754.
46. Verdugo-Castro, S., García-Holgado, A., Sánchez-Gómez, M.C. (2022). The gender gap in higher STEM studies: A systematic literature review. *Heliyon, 8(8)*.

47. Wilk, A., Lewicka, D., Karp-Zawlik, P., Pec, M. (2020). Percepcja uwarunkowań karier kobiet menedżerów średniego szczebla. *Annales Universitatis Mariae Curie-Skłodowska, sectio H–Oeconomia, 54(4)*.
48. Woods, A., Tharakan, S. (2021). *Hiring for diversity: The guide to building an inclusive and equitable organization*. John Wiley & Sons.
49. World Economic Forum (2022). *Global Gender Gap Report*. Retrieved from: https://www.weforum.org/publications/global-gender-gap-report.

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CHALLENGES OF THE FOOD INDUSTRY IN POLAND IN RELATION TO GROWING CONSUMER AWARENESS

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Purpose: The aim of the study is to examine the food market in Poland and show the most important challenges of this market in the context of growing consumer awareness.
Design/methodology/approach: To achieve the purpose of the article, literature and the latest industry reports on the food market in Poland were analyzed and surveys on consumer awareness were conducted.
Findings: Analysis and research have shown that consumer awareness (especially ecological and economic awareness) influences purchasing decisions on the food market.
The examined market is very dynamic, and the changes taking place in it require adaptation skills from enterprises, as shown by the supply turnover on the market in recent years.
Research limitations/implications: In such a dynamic market, research on consumer awareness and purchasing decisions should be repeated every year to be up-to-date and have a real impact on economic reality.
Practical implications: The results of analyzes and research may have a real impact on business practice. Food companies can use these guidelines on consumer awareness to ensure that their market behavior is appropriate not only from a business point of view, but also from a social and ecological point of view.
Social implications: A look at consumer awareness analysis may have an impact on social responsibility.
Originality/value: The author's own research and current analysis of behavior on the food market.
Keywords: consumer awareness, food market, challenges.
Category of the paper: research paper; viewpoint.

1. Introduction

Poland, as a European country, is at the forefront of the fastest developing economies, which is reflected in the growing ecological and economic awareness. The issue of consumer awareness, both in ecological and economic aspects, concerns many markets and industries. An example of a market in which consumer awareness has a strong impact on enterprises and their behavior is the food industry. The specificity of the food market in Poland results from

and depends on many conditions, both political, economic, social, ecological and meteorological. This dynamic market is full of challenges, and I can prepare for some of them - such as the introduction of legal restrictions, where the process takes months and sometimes years, but some events are unexpected and adaptation skills and appropriate response to them are crucial. The difficulty of the food market also lies in the presence of many different entities - from food producers to distributors. The decisive unit is the consumer, and it is his purchasing decisions that ensure the existence and development of enterprises on the market.

The article cites the challenges that food market enterprises have had to face in recent years. The results of own research on consumer awareness were also presented. The aim of this article is to examine the food market in Poland and show the most important challenges of this market in the context of growing consumer awareness.

2. Consumer awareness

Consumer behavior and their attitudes are characterized by great diversity and interdisciplinarity. The importance of consumer behavior can be related to economics, sociology and psychology. Some definitions emphasize the importance of consumer needs and define consumer behavior as a way of hierarchizing their needs (Rudnicki, 2012). Other explanations focus on the multitude of activities involved in consumer behavior and define them as everything that precedes, occurs during, and follows the consumer's purchase of goods and services (Falkowski, 2009). The complexity of this term and the factors influencing it also comes from the fact that it covers all activities related to the purchasing process, i.e. purchasing, possessing, using and evaluating products and services. The combination of many factors and stimuli often does not depend on the company itself (Burlita et al., 2020).

The determinants of consumer behavior can be determined in two ways - by factors that the consumer consciously reacts to and makes decisions under their influence, and by factors whose influence is independent of the buyer's will. It is not always possible to determine the degree of influence of a given factor and what determined the consumer to make a purchase decision (Zaniewska, Kobylińska, 2023). Consumer behavior and, consequently, purchasing decisions are shaped based on many economic, cultural, social and even ethical stimuli and factors. The importance of these factors is built not only by individual awareness, but also by society's awareness, which results mainly from the level of development of a given country.

Own research on consumer awareness took place in May 2024 through a survey. 204 people were surveyed and the survey concerned consumer awareness on the food market. Volunteers aged 18-65 took part in the study. According to the survey results, 82.4% confirm consumer awareness. Interestingly, 80% of the surveyed women consider themselves conscious consumers, while among the surveyed men this percentage is 85%. A total of 58.3% declare their ecological awareness to be good and very good, as shown in the chart below.

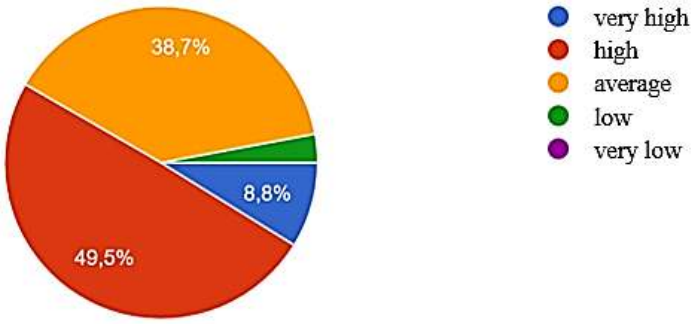

Figure 1. Survey question "How do you rate your ecological awareness".

Source: own study based on survey research.

Ecological awareness is the awareness of people's dependence on the rest of nature and the awareness of the impact that human activities have on the surrounding environment. It means not only the appropriate level of knowledge, but also its emotional assimilation, which causes specific purchasing decisions to be made (Sowa, 2018). Consumers' ecological awareness has a great impact on the food market. Their purchasing decisions are a sign of changes for food producers and distributors. The main change, for both health and environmental reasons, is the greater consumption of more environmentally friendly food and drink products (https://odr.pl/..., 2021). The ecological awareness of food market consumers is reflected in their purchasing choices, and the most desired products are the least processed, e.g. milk, water, coconut water or plant drinks.

Consumer awareness, especially in ecological aspects, is built on the basis of information channels. The results of the EFSA Eurobarometer show that the main source of information on risk factors related to food consumption in the EU is television (69%) and the Internet (46%). Other sources of information are: press (38%), radio (25%). Respondents from Poland indicated family and friends (38%) as sources of information more often than the press (23%). A significant number of respondents from Poland (58%) declared that they changed their purchasing decisions under the influence of information obtained about possible risk factors related to the consumption of given products, of which 22% changed them permanently (https://ncez.pzh.gov.pl/..., 2024).

Economic (or financial) awareness is a combination of financial knowledge and consumer behavior and attitudes. The level of economic awareness is difficult to estimate and depends on many factors, including: demographics, related to previous education, attitudes and economic experiences. An important factor, directly related to demographics, is the freedom and level of use of media and new technologies. Surveys of the economic awareness of Poles are carried out periodically by the National Bank of Poland (the last published ones are from 2020) and the results show that the self-assessment of Poles' economic knowledge is quite low, only 8% believe that their economic knowledge is high. It is also interesting that in the years examined, no one declared their knowledge to be at a very high level (https://nbp.pl/..., 2022).

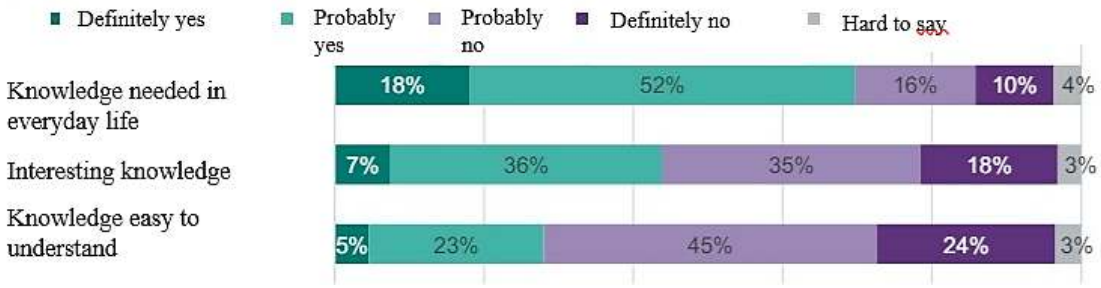

Figure 2. NBP survey: do you think that knowledge in the field of economics, finance and economics is necessary in everyday life, interesting and easy to understand?

Source: https://nbp.pl/wp-content/uploads/2022/09/wiedza-ekonomiczna-polakow.pdf.

Own research on consumer awareness also included the aspect of purchasing decisions based on income. It was examined whether the increase in earnings contributed to a change in the grocery shopping basket. Declaratively, 41.2% of respondents confirmed that as their income increases, they buy more quality things, even if they are more expensive.

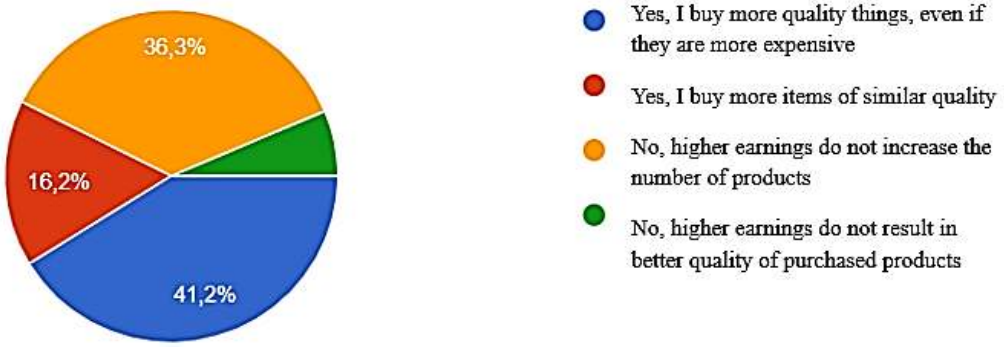

Figure 3. Survey question: Does your grocery shopping basket change as your earnings increase?

Source: own study based on survey research.

Consumer awareness is unquestionably important. It affects not only the social sphere and health, but also many commercial and production industries. A specific case of a market where consumer awareness is/should be a strong decision-making stimulus for many entities - from producers, distributors to consumers, is the food market.

3. Specificity of the food market in Poland

The food sector is one of the fastest growing branches of the Polish economy. Poland is the sixth largest market in Europe, and the potential - calculated in the number of inhabitants in 2023 - is nearly 37.7 million[1] (https://stat.gov.pl/..., 2023). The number of grocery stores in Poland, according to data from 2023, exceeds 90,000. Although the food industry still

[1] Data from the Central Statistical Office do not include Ukrainian citizens who came to Poland due to hostilities and received PESEL.

dominates in Poland in terms of the number of retail outlets, there is a clear trend of store closures. The grocery store sector is shrinking mainly with small, independent outlets. Retail chains such as the Portuguese Biedronka or the German Lidl are still growing in strength, both in terms of financial results and the number of stores in Poland. Local, independent stores are being replaced by another chain store - Żabka, the company opened 1,000 stores in Poland in 2023 alone. shops. There are 10,000 of them in total, which is over 11% of all grocery stores in Poland. For comparison, there are 850 Lidl Polska discount stores in Poland (less than 1% of all grocery stores in Poland).

For many years, the importance of large enterprises has been increasing in the Polish food industry, at the expense of medium, small and micro companies. This is evidenced by the increase in the share of the largest units in the value of sold production of this sector, the weakening position of small and medium-sized enterprises, and the decreasing share of micro companies. Data on the entity structures of individual departments producing food and beverages confirm large inter-industry diversification, which is also important for the functioning of food producers during the pandemic. Individual sectors of the food industry can be divided into (Szajner, Szczepaniak, 2020):

- highly fragmented, in which 20-40% of production is produced by small companies (bakery, milling, pasta production),
- fragmented, in which 10-20% of production is produced by small industrial companies (meat, fruit and vegetable, feed),
- with a high degree of concentration - sugar (in which 100% of production is produced by large companies), tobacco (98%), brewing (90%), soft drinks (78%), sweets (76%), dairy (72%), fish (70%) and durable confectionery, oil, food concentrates and spirits, in which over 60% of the sold production is produced by large companies.

Grocery stores in Poland have a strong influence on each other. The failure of some may be the success of others. Competition is most noticeable during holiday seasons, with special offers. However, cooperation between food market entities is mostly competitive rather than cooperative. An example of such competition is Biedronka and Lidl. Their marketing taunts have become the subject of both serious industry analyzes and internet jokes. However, it all comes down to one thing - increasing the popularity of brands or maintaining the popularity of these brands (https://businessinsider.com.pl/..., 2024). However, it should be emphasized that grocery stores are not the only entities operating on the food market in Poland. These are also food producers, distributors and entities providing indirect services such as handling, processing and storage.

The specificity of the food industry results from a variety of goods - in terms of quality, price, ecology, origin and durability. The food market in Poland is a difficult market, for example due to weather changes, on which the acquisition of raw materials and the entire production are strongly dependent. An important building block of the Polish food market is being a producer and exporter of fruit (apples, raspberries, black currants, blueberries),

vegetables, meat (poultry, pork), and dairy products. The processing industry in Poland also includes the production of tobacco and alcohol, which also belong to the list of food products. Polish producers are highly competitive both in the EU and in the world.

4. Selected challenges of the food market

The rules and norms prevailing on the food market are not always the same and the events they are subject to are often beyond their control. In recent years, many events in the economic, political and social sphere have been observed in Poland, which have transformed the functioning of this market.

4.1. Pandemic COVID-19

The economic reality on the food market has been disrupted by the outbreak of the COVID-19 pandemic and its consequences. Introducing restrictions on the number of people in stores, new health protection and hygiene rules, including: the obligation to wear masks, plexiglass windows at checkouts, as well as the increase in demand for online shopping were reflected in the financial results of food industry enterprises. However, food producers have been less affected by the effects of the COVID-19 pandemic than other industrial processing sectors, because the products manufactured in this sector are first-need products and are therefore characterized by lower income elasticity of demand. However, it is not clear that this impact was clearly negative. Changes in rules forced enterprises to be even more flexible and quick in adapting to new conditions. The fact that society bakes bread more at home translates into lower bread sales, but also into an increase in demand for flour and yeast. The biggest problem for every company was maintaining production in the event that the plant was infected with the SARS-CoV-2 virus. Such cases have already occurred, but food companies dealt with them and there was no need to completely stop production. The actions taken concerned the reorganization of activities in the areas of departments where infections occurred among the staff. The preventive actions undertaken by food companies undoubtedly contributed to mitigating potential problems on the supply side, but despite this, production declines occurred in some market segments (Żurek, Rudy, 2024).

4.2. Brexit

Brexit also undoubtedly had an impact, in particular on some food producers in Poland. The impact of Brexit on the food market in Poland results from significant trade exchanges between the UK and Poland before Brexit. This primarily concerns the availability and prices of products from Great Britain that are sold in Poland.

In 2019, the value of poultry meat exports to the British market alone accounted for 14% of all exports from Poland. Great Britain was one of the most important buyers of Polish meat products such as sausages, cold cuts, unprocessed pork and beef. From January 31, 2024, EU exporters of chilled and frozen meat, fish, cheese and dairy products must present sanitary certificates signed by a veterinarian at the border. This introduces both delays and price increases. And from May 1, 2024, physical shipment controls and higher costs have also been introduced, which further limit the availability and freshness of food products such as cold meats, cheeses, pasta and olive oils. In addition, the British market was an important importer of chocolate products, buttermilk, yogurts, bread, cheese and cigarettes. It is also important that until 2019, Poland had a significant surplus in the exchange of agricultural and food products with Great Britain. In 2019, the surplus amounted to EUR 2,140 million (https://foodfakty.pl/..., 2021).

Brexit not only means restrictions on the freedom of goods provided by the European Union, but also introduces numerous border controls in Great Britain, which make it difficult to import food products from EU countries. According to the British government, such controls will protect Great Britain against the appearance of diseases and plagues and will equalize the operating conditions for British exporters. In practice, such restrictions caused a number of delays in port operations and prompted some British exporters to refrain from selling (https://www.rp.pl/..., 2024).

4.3. War in Ukraine

Another challenge with a political, social and economic background is the war in Ukraine. This affects both the demand and supply sides of the Polish food market. "Russian aggression against Ukraine creates a high risk of a short-term supply shock on the food market" (https://www.pkobp.pl/..., 2024). The limited flow of materials and raw materials was further hampered by the fact that Ukraine is not a member state of the European Union. Completely unblocking access to raw materials had the opposite effect - purchasing Ukrainian grain cheaply significantly influenced the price attractiveness offered by Polish producers. As a result, it caused a storm of negative emotions. This situation shows that even extraordinary market situations, such as war, must have their own legal framework to secure the interests of all countries involved.

Poland is not an important trade partner of Russia and Ukraine in the field of food. However, the side effects are much broader. There are warnings that the war, along with extreme weather caused by climate change and the post-pandemic economic shock, will fuel a global food crisis. The fertilizer market is closely linked to the food market. A few weeks ago, the two largest producers of nitrogen fertilizers in Poland announced the reduction or temporary suspension of production due to its unprofitability at current gas prices. Previously, similar decisions were made by major manufacturers in the European market (Perchla-Włosik, Wardzała, 2023).

5. Conclusions

The challenges that food market enterprises in Poland must face are related not only to extraordinary events such as a pandemic, Brexit or war, but also to the natural consequences of national and international economic decisions of countries. The free market in Poland is, on the one hand, a pass for many entrepreneurs, but also the elimination of local units, which is shown by the distribution of foreign capital on the Polish food market. Increased consumer awareness is not the only obvious, foreseeable challenge regarding the future of the food market. Growing EU requirements regarding environmental friendliness – primarily the green deal – and unrelenting negative social attitudes regarding this issue - the farmers' strike are just some of them. Undoubtedly, the interesting, dynamic but also difficult food market will face many systemic and situational changes in the coming years.

All these events had a direct or indirect impact on the economic situation in Poland in 2021-2023 and, consequently, on the growing level of inflation. High inflation and decreasing consumer purchasing power affect consumers' willingness and ability to make purchases. The results of research conducted in May 2024 show that a change in the financial situation does not always influence the purchasing decisions of Poles.

And finally, we should not forget about issues related to consumers themselves, or more broadly - the entire society. Consumer awareness, understood in so many aspects: ecological, economic, cultural, ethnic, aesthetic and ethical, is an important decision-making factor in purchases, also on the food market. Enterprises operating on the food market cannot ignore this issue. What is crucial is not only the awareness of the growing knowledge about the quality, origin, impact on health and economy of products, but also the adaptive skills of enterprises and their behavior on the market, so as to be able to use changing conditions to their advantage.

References

1. Burlita, A. (2020). *Zachowanie konsumentów. Wybrane problemy.* Warszawa: PWE, p. 13.
2. Falkowski, A., Tyszka, T. (2009). *Psychologia zachowań konsumenckich*. Gdańsk: Gdańskie Wydawnictwo Psychologiczne, p. 12.
3. https://businessinsider.com.pl/finanse/handel/lidl-kontra-biedronka-beda-ofiary-wojny-cenowej/nswhgyg
4. https://foodfakty.pl/jaki-wplyw-brexit-bedzie-mial-na-polska-branze-spozywcza
5. https://nbp.pl/wp-content/uploads/2022/09/wiedza-ekonomiczna-polakow.pdf
6. https://ncez.pzh.gov.pl/abc-zywienia/swiadomosc-konsumenta-w-swietle-raportu-efsa/
7. https://odr.pl/2021/12/09/profilaktyka-prozdrowotna-a-swiadomosc-konsumencka/

8. https://stat.gov.pl/obszary-tematyczne/ludnosc/ludnosc/powierzchnia-i-ludnosc-w-przekroju-terytorialnym-w-2023-roku,7,20.html
9. https://www.pkobp.pl/centrum-analiz/analizy-sektorowe/rolnictwo-i-przemysl-spozywczy/wplyw-wojny-w-ukrainie-na-sektor-rolnospozywczy/
10. https://www.rp.pl/handel/art40235971-brexit-uderza-w-import-zywnosci-brytyjczycy-narzekaja-na-nowe-przepisy
11. Perchla-Włosik, A., Wardzała, J. (2023). The war in Ukraine as a determinant of changes in consumer behavior in Poland and in the world. Example of food, real estate and luxury markets. *Studia de Securitate, no. 13*, p. 99.
12. Rudnicki, L. (2012). *Zachowania konsumentów na rynku.* Warszawa: PWE, p. 10.
13. Sowa, F. (2018). Świadomość ekologiczna i jej wpływ na ekologizację społeczeństwa i gospodarki. *Rynek-Społeczeństwo-Kultura, no. 4*, p. 37.
14. Szajner, P., Szczepaniak, I. (2020). Ewolucja sektora rolno-spożywczego w warunkach transformacji gospodarczej członkostwa w UE i globalizacji gospodarki światowej. *Problems of Agricultural Economics, no. 4*, p. 20.
15. Zaniewska, M., Kobylińska, U. (2023). Wybrane zachowania konsumentów na rynku nieruchomości w okresie pandemii COVID-19. *Academy of Management, no. 7*, p. 214.
16. Żurek, J., Rudy, M. (2024), Impact of the COVID-19 Pandemic on Changes in Consumer Purchasing Behavior in the Food Market with a Focus on Meat and Meat Products – A comprehensive literature review. *Foods, No. 13*, p. 20.

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PARAMETERIZATION OF INFORMATION CHANNELS IN STRATEGIC DECISION-MAKING – A CASE STUDY

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Purpose: The study addresses the problem of parameterization of information channels, indicating their impact on strategic decision-making in the enterprise. The study is an attempt to answer the research question - how does the parameterization of information channels moderate strategic decision-making in the enterprise?
Design/methodology/approach: In the article, the literature study method was applied as well as the financial analysis of data contained in the financial statements of the examined company was conducted. Initially, the structure of assets and liabilities of the examined company was analyzed. Then, the research also used the ratio analysis method. Financial liquidity, profitability and debt ratios were analyzed. The choice of these indicators resulted from the role they play in financial analysis.
Findings: The publication contributes to the discussion on the extent to which enterprises use the processes of parameterization of information channels. Ratio analysis of financial statements allows for the interpretation of the company's results. It is therefore a basic tool for identifying threats in the context of business continuity risk, allowing for making effective strategic decisions related to maintaining the optimal financial condition of the enterprise.
Originality/value: The publication constitutes the practical analysis of the company's financial situation, including business continuity risk assessment. The publication may constitute a reference point for other enterprises operating on the non-ferrous metal market and contributes to increasing awareness of the constant need to analyze the financial condition of the enterprise.
Keywords: decision-making, assessment of the company's financial condition, ratio analysis.
Category of the paper: Research paper.

1. Introduction

Effective decision-making in a dynamic business environment depends on access to the widest possible range of information about this environment (Wyskwarski, 2018). When managers encounter limitations in access to data, they must conduct the analysis of markets, competitors and their own enterprise. In such circumstances, it becomes crucial to use advanced financial analysis methods that provide accurate information about the state and conditions of the company's operations (Nowak, 2018; Chytilová, Talíř, 2024a). Financial indicators are important because they confirm the effectiveness of decisions and constitute valuable support in the decision-making process. Parameterization of information channels as a process of identifying and describing various parameters that are important for a given field of management makes it possible to adapt the process of transmitting information to specific needs and conditions and allows to track the flow of information and analyze its effectiveness (Floater, Hormann, 2005). This study attempts to answer the research question: how does the parameterization of information channels moderate strategic decision-making in the enterprise? The research method used in the work is literature studies and financial analysis in the form of a case study.

2. Strategic decision – making as a key element of management

Decision-making is a priority element of the management process (Jankowska-Mihułowicz, 2012). In various studies in the field of management, there is a range of definitions of management that consistently emphasize the importance of achieving set goals and effects (Mikuła, 2018). Achieving the expected performance depends on making many management decisions that are based on solid data that enable the analysis and assessment of economic processes (Wasilczuk, 2015). The decision-making process is the transformation of data into managerial actions (Trocki, 2019). The analysis of various options is an important part of the decision-making process, since its accuracy determines how effective the final decision will be. This requires not only recognizing and defining the decision-making problem, but also identifying various operation options and selecting the optimal solution to be used (Stabryła, 2010; Chytilová et al., 2024). In other words, decision-making is the process of selecting a solution that meets unique criteria that enable finding an acceptable compromise through which the decision can be implemented. The decision-making procedure in the company needs regular verification using appropriately selected indicators and methods (Bobruk, 2022).

3. Monitoring financial information flow metrics in the company's decision-making processes

Instruments used to parameterize information transmission channels usually focus on methods and strategies for solving financial issues (Romanowska, Melnarowicz, 2020). Financial statements are a key source of data on the operating results of enterprises (Polańska, Rytkowska, 2023). The assessment of various selection options in the context of parameterization of information channels can be effectively carried out using ratio analysis, which complements the analysis of financial statements (Lesiak, 2022). In the literature on financial analysis, indicators are defined as relative values that allow for the analysis and understanding of various economic aspects of the company's operations. The analysis based on indicators is an advanced stage of the initial assessment of financial statements (Wilczyńska, 2018). It uses ratios to show the relationship between important values found in the balance sheet, profit and loss statement, cash flow statement and statement of changes in equity. Financial indicators function as measures of the circulation of economic values in the enterprise and as sources of data for many stakeholder groups (Jerzemowska, Hajduk, 2015).

When analyzing metrics used to assess the selection in parameterization of information channels, it is important to focus on aspects of assessing the condition of the entire enterprise. The financial condition of the enterprise is evaluated taking into account both internal factors and external conditions in which the enterprise operates (Nestorowicz, 2015; Chytilová, Talíř, 2024b). Assessing the internal aspects of the company requires paying attention to the current state of resources, their durability and the possibility of converting them quickly into cash. The analysis of these elements allows for assessing the asset and financial condition, profitability and ability to settle liabilities. In the context of external aspects, the position of the company in relation to its business environment and competitors is analyzed (Mesjasz-Lech, Skowron-Grabowska, 2016). The most important financial indicators that should be monitored in every company allow for assessing the company's ability to repay current liabilities and maintain financial liquidity and these are financial liquidity indicators. Debt ratios, on the other hand, provide information about the company's debt burden and capital structure. In turn, profitability indicators - such as return on sales (ROS), return on assets (ROA) or return on equity (ROE) - assess the company's ability to generate profit. The last group of basic indicators are operational efficiency indicators, which indicate how effectively the company uses its resources (Sierpińska, Jachna, 2004).

The above-mentioned indicators are crucial for assessing the financial condition of the enterprise, managing its resources and strategic planning. However, sometimes it is necessary to conduct a deep analysis of various aspects of the company's operations, which is crucial for understanding its solvency, profitability, operational efficiency and strategic decision-making. Financial ratios provide information about various areas of enterprise activity, making ratio

analysis an indispensable instrument for the enterprise management board, investors and financial analysts (Dyduch, 2015).

4. Parameterization of information channels in the X company – a case study

The scope of activity of the analyzed company is wholesale and retail sale of metals and metal ores, management of metal waste and scrap, and production of copper wire and profiles. The X company has been operating since 2003. From the very beginning, the company has been a supplier of a wide range of non-ferrous metal products. To assess the company's financial condition, its financial statements for 2020-2022, published in Internetowy Monitor Sądowy i Gospodarczy - IMSiG (Internet Court and Economic Journal), were used. The company's bodies are the Shareholders' Meeting and the Management Board. At the end of the 2021 financial year, the share capital structure was as follows: total: 330 (number of shares), 330,000.00 (nominal value of shares), 100% (share in the company's share capital). Basic financial information about the analyzed company is included in Table 1.

Table 1.
Balance sheet of the analyzed company for 2020-2022

	2020	2021	2022
A. Fixed assets	**43.84%**	**43.94%**	**26.99%**
I. Intangible and legal assets	0.00%	0.00%	0.03%
II. Tangible fixed assets	99.81%	96.18%	99.61%
III. Long-term receivables	0.00%	0.00%	0.00%
IV. Long-term investments	0.00%	0.00%	0.00%
V. Long-term accruals	0.19%	3.82%	0.36%
B. Current assets	**56.16%**	**56.06%**	**73.01%**
I. Inventories	42.00%	38.98%	35.19%
II. Short-term receivables	56.00%	55.73%	59.91%
III. Short-term investments	1.80%	5.05%	1.93%
IV. Short-term accruals	0.20%	0.24%	2.98%
Total assets	**100%**	**100%**	**100%**
A. Equity	**43.06%**	**44.31%**	**42.67%**
I. Share capital	0.48%	0.46%	0.30%
II. Supplementary capital	93.41%	95.27%	66.26%
VI. Net profit	6.11%	4.28%	37.12%
VII. Write-offs from net profit during the financial year (negative value)	0.00%	0.00%	-3.68%
B. Liabilities and provisions for liabilities	**56.94%**	**55.69%**	**57.33%**
I. Provisions for liabilities	0.23%	0.23%	0.19%
II. Long-term liabilities	32.57%	31.81%	16.72%
III. Short-term liabilities	55.61%	54.19%	73.57%
IV. Accruals	11.59%	13.77%	9.52%
Total liabilities	**100%**	**100%**	**100%**

Source: Based on IMSiG.

The balance sheet of the company for 2020-2022 is presented in percentage terms in relation to the balance sheet total and in relation to the main parts of assets and liabilities, i.e. fixed and current assets, as well as equity and liabilities and provisions for liabilities. This made it possible to expand the research perspective to the main balance groups. In the empirical part of this study, the structure of assets and liabilities of the examined company was analyzed. In the further part of the research, the indexing method was also used. Financial liquidity, profitability and debt ratios were analyzed. The choice of these indicators was deliberate and resulted from their role as basic measures of financial analysis. The values of the calculated financial ratios of the examined enterprise are presented in Table 2.

Table 2.
Selected financial indicators of the analyzed company for 2020-2022

Indicators examined\Years examined	2020	2021	2022	Recommended values
Asset and capital structure indicators				
Equity to fixed assets ratio	0.98	1.01	1.58	≥1
Fixed capital to fixed assets ratio	1.55	1.57	2.09	≥1
Asset immobilization ratio	78%	78%	37%	-
Liquidity ratios				
Current ratio	1.77	1.86	1.73	1.2 to 2
Quick ratio	1.03	1.13	1.12	about 1
Immediate ratio	1.03	1.13	1.07	-
Working capital	39 422 667	42 283 164	78 584 449	Positive values
Profitability indicators				
Return on Sales (ROS)	1.05%	0.72%	5.44%	Positive values
Return on Assets (ROA)	2.63%	1.90%	15.84%	Positive values
Return on Equity (ROE)	6.11%	4.28%	37.12%	Positive values
Debt ratio				
Total debt ratio	57%	56%	57%	Below 57%

Source: Own calculations based on IMSiG.

5. Analysis of the results

The analysis of the results of the X company indicated in the financial statements allows for the observation that in the years 2020 and 2021 the company achieved similar values of most balance sheet components. The value of the balance sheet total was PLN 90 million in 2020 and PLN 91.5 million in 2021. The value of current assets and fixed assets was also at a comparable level, as was the value of equity and external capital in both mentioned years.

The situation of the analyzed entity changed in 2022. The balance sheet total increased by approximately 56% compared to 2021, which amounted to approximately PLN 91 million. Such a significant increase in the balance sheet total was the result of an increase in net sales revenues, which increased by approximately 74% compared to 2021. The increase in net sales revenues resulted in an over tenfold increase in net profit, which amounted to over PLN 40

million (of which 10% was allocated for dividend payout) and an over 100% increase in short-term receivables in 2022.

On the side of fixed assets, the value of tangible fixed assets is noteworthy, reaching a similar level throughout the analyzed period, approximately PLN 70 million. In 2022, the value of inventories also increased significantly, which can be justified by the increase in sales revenues and the need to maintain high inventory levels to ensure continuity of production and sales.

It should be emphasized that the assets of the examined company are financed with external capital at the level of approximately 57% throughout the analyzed period. This result is a limit value for this indicator, thus the company's situation in this respect requires a broader analysis. However, taking into account the value of supplementary capital from the generated profit and the value of short-term receivables, the total value of which exceeds the value of external capital, the risk related to the total debt ratio is significantly minimized. This may also explain why the company maintains relatively low reserves for liabilities. It is worth adding that in the analyzed period, approximately 10% of foreign capital reflects the level of the company's accruals, which are the result of received subsidies.

Equity to fixed assets ratios and fixed capital to fixed assets ratio reached the recommended values in all years examined. The asset immobilization ratio was very good for an industrial enterprise.

The high level of cash in hand and on accounts means that all the liquidity indicators reached the recommended levels, and working capital achieved very high positive results in the X company, which means that the company has no problems with settling its liabilities. All the profitability indicators are positive, which is assessed positively, although their results in 2020 and 2021 were rather low, while 2022 brought an increase in the value of all the tested profitability indicators.

The company's analysis based on financial assessment indicators proves the good condition of the company. Very good profit for 2022, the highest in the company's history, and very good liquidity result in the fact that the company has security allowing for positive forecasts for its further operations. To sum up, based on the analysis of the results presented in the financial statements, it can be concluded that the accumulated funds allow for financing current operations mainly from external capital. Working capital remained at a safe, positive level in the years 2020-2022, and the appropriate values of liquidity ratios are also noted. The financial statements for 2020-2022 show that the company is profitable, and the level of profitability should be considered satisfactory.

6. Discussion

Based on the analyzed data, it should be concluded that the company's situation in the examined period is stable, which is confirmed by its financial results. It is worth emphasizing that in 2019, the company received financing from the National Center for Research and Development of nearly PLN 5.5 million. In 2020, the public aid the company received amounted to PLN 4.1 million. In 2021, on the other hand, the value of public aid obtained by the company amounted to PLN 1.5 million.

According to the data published on the Rejestr.io Fundacja Moje Państwo portal, the company also received funding from public aid of PLN 2.2 million in 2022 guaranteed by Bank Gospodarstwa Krajowego. Moreover, the X company is the beneficiary of numerous projects co-financed from public funds, which proves the company's potential to conduct R&D activities. Based on the above analysis and the specific nature of the company's operations, its financial condition is assessed as good and its financial risk as low.

7. Summary

By parameterizing information channels based on data from financial statements in the examined enterprise, it is noted that possessing current and up-to-date information on the financial condition of the enterprise has a decisive impact on strategic decision-making in the enterprise (Edwards, 1954). The publication helps confirm that enterprises that monitor their financial situation on an ongoing basis, using the process of parameterization of information channels, gain an advantage in the competitive market and opportunities to survive in a turbulent environment. When answering the research question: how does the parameterization of information channels moderate strategic decision-making in the enterprise? - the answer comes to mind that correctly performed parameterization of information channels provides the information necessary to identify threats in the context of business continuity risk, thus allowing for making effective strategic decisions in the enterprise. As the conducted research has indicated, the analyzed company has a stable and safe financial situation, therefore strategic decisions in this company are not burdened with business continuity risk. Making strategic decisions in the event of a threat to the continuation of the company's operations is associated with high risk, therefore the parameterization of information channels using indicators in the field of financial analysis contributes to an increase in awareness of the constant need to analyze the financial condition of the company (Schwartz, 2016).

References

1. Bobruk, M. (2022). Zastosowanie analizy ekonomicznej w procesach decyzyjnych w obszarze zarządzania innowacjami. *Myśl Ekonomiczna i Polityczna*, *No. 1(72)*, pp. 95-114.
2. Chytilová, E., Talíř, M. (2024a.). Digitalization of BSR in the recession. *Management Science Letters, 14.* North Vancouver BC, Canada: Growing Science, pp. 139-150.
3. Chytilová, E., Talíř, M. (2024b). Companies' performance and behaviour responding tocrisis during Covid-19 pandemic: a case study of the Czech Republic. *Entrepreneurship and Sustainability Iss. 11(3)*, pp. 305-320. Retrieved from: http://dx.doi.org/10.9770/jesi.2024.11.3(21).
4. Chytilová, E., Talíř, M., Straková, J., Dobrovič, J. (2024). Impact of digital procurement on economic resilience of enterprises during COVID-19. *Journal of International Studies*, *17(1)*, pp. 188-204. doi:10.14254/2071-8330.2024/17-1/11.
5. Dyduch, J. (2015). Środowiskowe informacje finansowe w raportach rocznych spółek publicznych z sektora chemicznego. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu, No. 396*, pp. 28-38.
6. Edwards, W. (1954). The theory of decision making. *Psychological bulletin*, *51(4),* 380.
7. Floater, M., Hormann, K. (2005). Surface parameterization: A tutorial and survey. *Advances in Multiresolution for Geometric Modelling*, pp. 157-186.
8. Jankowska-Mihułowicz, M. (2012). Decyzyjność menedżerów w praktyce i teorii zarządzania. *Studia i Prace Kolegium Zarządzania i Finansów, z. 115*, pp. 74-83.
9. Jerzemowska, M., Hajduk, A. (2015), Wpływ rentowności przedsiębiorstwa na strukturę kapitału na przykładzie spółek akcyjnych notowanych na Giełdzie Papierów Wartościowych w Warszawie. *Zeszyty Naukowe, No. 2(938).* Uniwersytet Ekonomiczny w Krakowie, pp. 45-57.
10. Lesiak, M. (2022), Analiza wskaźnikowa jako narzędzie stosowane do oceny kondycji finansowej spółki. *Przedsiębiorczość - Edukacja*, *Vol. 18, No. 1*, pp. 31-40.
11. Mesjasz-Lech, A., Skowron-Grabowska, B. (2016). Competitive processes on foreign markets and the intelligent enterprise. *Journal of Management and Financial Sciences*, *Vol. 9, No. 24*, pp. 133-146.
12. Mikuła, B. (2018). Zarządzanie oparte na wiedzy - podstawowe założenia. *Studia Ekonomiczne. Gospodarka - Społeczeństwo - Środowisko, No. 2,* pp. 34-46.
13. Nestorowicz, R. (2015). Znaczenie sprawozdawczości finansowej w ocenie wyników i zarządzaniu przedsiębiorstwem. *Studia i Materiały. Miscellanea Oeconomicae*, *R. 19*, *No. 3*, pp. 271-282.
14. Nowak, E. (2018*).* Kierunki wykorzystania metod ekonometrycznych w analizie informacji dostarczanych przez system rachunkowości. *Prace Naukowe Uniwersytetu*

Ekonomicznego we Wrocławiu [Research Papers of Wrocław University of Economics], No. 506, pp. 84-92.

15. Polańska, K., Rytkowska, W. (2023). Wpływ badania sprawozdania finansowego na wizerunek i wiarygodność przedsiębiorstwa. *Prace Naukowe - Problemy współczesnej rewizji finansowej.* Uniwersytet Ekonomiczny w Katowicach, pp. 49-57.
16. Romanowska, M., Melnarowicz, K. (2020). Strategies for Innovative Business in Business Groups. *Przegląd Organizacji*, *No. 3,* pp. 3-11.
17. Schwartz, M.S. (2016). Ethical decision-making theory: An integrated approach. *Journal of Business Ethics*, *139*, pp. 755-776.
18. Sierpińska, M., Jachna, T. (2004). *Ocena przedsiębiorstwa według standardów światowych.* Warszawa: PWN.
19. Stabryła, A. (2010). Analiza decyzyjna w projektowaniu strategii zarządzania przedsiębiorstwem. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu*, *No. 116*, pp. 407-417.
20. Trocki, M. (2019). Podejścia badawcze w zarządzaniu projektami - geneza i ewolucja *Przegląd Organizacji*, *No. 3*, pp. 3-9.
21. Wasilczuk, J. (2015). Płeć a motywacje przedsiębiorcze oraz podejmowane przez mikroprzedsiębiorców decyzje zarządcze. *Problemy Zarządzania*, *Vol. 13, No. 4(56)*, pp. 115-130.
22. Wilczyńska, M. (2018). Analiza wskaźnikowa jako narzędzie wykorzystywane do oceny sytuacji finansowej przedsiębiorstwa. *Finanse, Rynki Finansowe, Ubezpieczenia*, *No. 2(92)*, pp. 185-194.
23. Wyskwarski, M. (2018). Kokpit menedżerski w małym przedsiębiorstwie. *Nierówności Społeczne a Wzrost Gospodarczy*, *z. 53*, pp. 365-375.

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SECURITY OF CLOSED – CIRCUIT TELEVISION – CASE STUDY

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Purpose: The purpose of this paper is exemplification which illustrates the application of the simple analytic method to the analysis of the performance of a closed-circuit television system operated by a large nationwide organisation.
Design/methodology/approach: This straightforward approach conduce to readily adopted by businesses of varying sizes, enables the organisation and analysis of information pertaining to the entirety of an organisation's operations, structure and strategic orientation. The well known method SWOT is used.
Findings: The work shows the advisability of using the SWOT method to analyze the performance of CCTV. It is noted that the above method can serve as a preliminary stage for an in-depth analysis of the risk of CCTV operation and the selection of an appropriate organizational strategy in this matter.
Originality/value: The principal benefit of this approach is its versatility and simplicity. However, this also represents a potential drawback, namely the subjectivity that experts may introduce when performing it. The authors illustrated the efficacy of this approach in formulating a strategy for addressing a problem by constructing a dependency matrix between external and internal factors. This matrix enables the evaluation of the operational efficacy of a secure system, such as a closed-circuit television system, and the formulation of recommendations for its future development.
Keywords: Strengths, Weaknesses, Opportunities, Threats (Swot), Worst Case Analysis, CCTV (Closed-Circuit Television), FAT (Factory Acceptance Test).
Category of the paper: Case study.

1. Introduction

Security is a significant factor influencing the decision of business owners, irrespective of their size, to adopt closed-circuit television (CCTV). This early 20th-century invention has a variety of applications, both in a broader urban context and in a more limited domestic context. One of the fundamental components of an effective security system for safeguarding individuals

and assets on a given premises is the continuous monitoring of the premises through the use of video surveillance technology. In practice, the cameras are frequently utilised by companies across a range of industries, with an increasing prevalence in communal buildings and commercial premises.

The main objective of CCTV is to enhance the level of security, including the expeditious identification of potential threats and the implementation of suitable countermeasures.

The paper describes a certain exemplification of the use of the SWOT method to analyse the performance of a closed-circuit television system. The objective of this case study is to demonstrate the utilisation of the findings derived from the SWOT analysis. This easy-to-use method used in business can be successfully applied in small, medium and large organisations to organise and analyse information for every facet of the organisation's operations, structure and strategy. The principal benefit of this approach is its versatility and simplicity. However, this also represents a potential drawback, namely the subjectivity that experts may manifest when performing it. The paper will demonstrate the utility of this method in the selection of an optimal strategy for the resolution of a given problem. This is achieved through the creation of a dependency matrix between external and internal factors, which allows for the assessment of the operational quality of a secure system, such as a CCTV system. Furthermore, it enables the formulation of guidelines for the continued development of the system.

The selection of an appropriate system is not merely a matter of ensuring security or the prevention of unfavourable occurrences. The selection of the optimal solution is contingent upon a number of factors, including economic considerations, functionality, and the potential for installation and the associated limitations.

By undertaking a comprehensive risk and weakness **assessment** of the designed system, a proposal for a solution to the identified problem can be formulated. In order to conduct a comprehensive analysis of the functionality of the designed system, we will utilise an illustrative analogue closed-circuit television system of a prominent nationwide organisation, designated here as "ABC" (in the paper, the name of the organisation is altered). This system operates on a national scale in accordance with the Polish standard PN-EN 62676-4.

2. Closed-circuit television

Video surveillance, often referred to as closed-circuit television (CCTV) significantly increases the security level of the protected facility (Gaździcki, 2024). Closed-circuit television (CCTV) is a system whose basic elements are cameras. While the deployment of just cameras in strategic locations on a site allows for the tracking of various activities, this is insufficient for the effective implementation of closed-circuit television**.**

In the paper on principles for checking the effectiveness of closed-circuit television, ten principles for the responsible implementation of CCTV are cited, which were formulated by Nancy G. La Vigne of the Urban Institute in Washington, D.C. These principles apply to closed-circuit television in urban spaces, but a significant proportion of them also have relevance to private use.

Principles of closed-circuit television effectiveness (Kabzińska, Szafrańska, 2018):

1. identify the needs for which closed-circuit television is to be responsible and the budget for the investment,
2. planning (prior to investment) the principles of camera management, the necessary infrastructure and other costs that may arise from the operation of the monitoring over time,
3. selecting camera locations to ensure good visibility,
4. considering integrating closed-circuit television with other technologies (e.g. intelligent surveillance systems, crime maps),
5. balancing between the usefulness of the monitoring and the protection of privacy and other civil rights,
6. considering the benefits and costs of introducing cameras based on continuous active monitoring (uninterrupted observation of camera images by operators),
7. integrating the surveillance cameras into existing practices and procedures for ensuring public safety and order,
8. forming and maintaining realistic expectations of the quality of monitoring records,
9. using closed-circuit television as a tool to complement existing prevention (e.g. police patrols), identification and reconnaissance activities,
10. being aware of the evidentiary potential of closed-circuit television recordings, which can only (or as much as) complement other means of evidence (e.g. witness statements).

The legal basis for using CCTV depends on the situation – it will be different at work, at home and when it's related to a city or county. It would seem reasonable to posit that the primary obligation is to notify the monitoring operation. The use of a hidden camera could result in legal ramifications.

The basic set of components of a closed-circuit television system consists of (Gaździcki, 2024):

- cameras – which read and transmit images in real time to the recorder,
- a video recorder – which, thanks to its software, enables the reading of images from cameras on the screens of the monitors connected to it, as well as the recording of images on a hard drive connected to it or, in the case of digital video recorders (DVRs), also on a server,
- monitoring software,
- a keyboard – to control the system,
- a monitor (or more) – with which it is possible to observe the image from the cameras.

It is a closed-circuit because all its components are tightly interconnected. Unlike conventional television, this system is designed for a limited audience. Cameras, as the most important component of a CCTV system, which allow dangerous situations to be detected completely remotely, without leaving the observation post and control keyboard panel. The CCTV system plays a vital role in ensuring the security of the site, providing invaluable assistance to the security personnel and enhancing their capabilities. A CCTV system can operate by connecting individual devices together either wired – using coaxial cables or network cables – or wirelessly**,** using an internet connection. The choice of the type of equipment will therefore determine its installation. It should be noted here that the most important components that make up a closed-circuit television system are the cameras and the video recorder.

The image transmitted from the cameras is only received at the receiving centre. In analogue systems, the images from the cameras are recorded by the video recorder on video tapes for later playback. Keyboards are also connected to the video recorder to control the system, including panning and focusing the image. However, these are analogue systems that are increasingly being displaced by modern digital systems.

The primary purpose of monitoring is to increase the level of security, including in particular the rapid identification of potential threats and the taking of appropriate countermeasures. Modern monitoring allows 24/7 observation of the protected objects and thus allows to:

- increase protection against burglary, theft and robbery,
- reduce the cost of employing physical security staff,
- increase productivity in industrial buildings,
- improve the company's image.

CCTV systems have the following advantages:

- the ability to detect the presence of unwanted people and dangerous situations,
- 24-hour supervision supported by a member of staff or not,
- guaranteeing a sense of security in public places,
- providing evidence in the case of misdemeanours and crimes committed and caught on camera.

Depending on one's subjective opinion, a CCTV system may or may not be considered necessary on a property. Furthermore, the surveillance system can be controlled remotely from the control room and the cameras can operate continuously, providing uninterrupted images from sensitive locations. Therefore, this system is used by many commercial establishments, services, workplaces and even private users.

The presence of IP cameras often makes potential perpetrators choose not to commit a crime for fear of being recognised. Closed-circuit television footage is often used to apprehend the offender and explain the resulting incidents. The use of CCTV very often facilitates the work of those supervising motorways and the traffic that is on them. This allows them to deploy units

in a quick and organised manner in the event of an accident of some kind or to pass on information about traffic jams. CCTV systems also increase the sense of security on public transport, informing the services when a crime has occurred so that the police can respond more quickly and get to the scene. Additionally, cameras are utilised by proprietors of commercial and service establishments, including shopping centres, hotels and restaurants, to guarantee the security of their clientele and personnel.

The operation of closed-circuit television is straightforward. The cameras, deployed in various locations, transmit images to a video recorder, which allows them to be read on monitors and allows them to be recorded on an external hard drive or servers. In order for devices to communicate with each other, they are connected by cables, or in modern systems by transmitters, using Wi-Fi. Thanks to Internet access, they can in turn transmit images directly to users' mobile devices, who can thus remotely monitor the facility from anywhere.

The cameras must be connected to a video recorder or video server, as must the monitor(s) that allow the image to be read, the control keyboard and external storage media that allow the surveillance image to be recorded. Furthermore, a surveillance system installed on a server or video recorder is required to carry out surveillance. Only a system configured in this way enables video tracking.

Closed-circuit television is a system of cameras installed on the premises to track activity. Its operation is based on the installation of CCTV cameras and the tracking of all movements and processes on the premises through them**.** Due to the extensive functionality of CCTV cameras, they are used in various types of facilities.

Closed-circuit television consists of several different pieces of equipment because the installation of cameras alone does not allow for surveillance. Conducting surveillance with cameras definitely makes it easier to identify potential threats on the protected premises. Regardless of how the premises are being used. However, the specifics of a particular site may limit the effectiveness of particular cameras**,** so it is advisable to select the equipment that works best for it. Equipment in analogue monitoring is mainly used to track activity at close range.

Analogue cameras have many advantages:

- Simpler to install and cheaper than their digital counterparts – we connect each camera to a video recorder, meaning we have no devices between the camera and the video recorder.
- Stable transmission without delay – live viewing is real-time, without delay.
- Long signal transmission distance – using coaxial cable, the maximum distance between the camera and the video recorder is up to 0.5 km.
- Compatibility – the vast majority of the system's equipment supports all standards, making it possible to freely combine cameras and recorders from different manufacturers.

- Unified system – the heart of the entire system is the video recorder and it manages all the cameras, is responsible for intelligent event detection and alerts and generates notifications.
- Independence from the Internet network – Analogue cameras can record events regardless of Internet access due to the camera's direct connection to the video recorder via a signal cable.

Disadvantages of analogue cameras:

- They require a cable to be run to each unit, which is not always possible due to building installation constraints.
- Difficult to configure cameras – the OSD menu in analogue cameras requires technical expertise to properly configure the entire system.
- Fewer image adjustments – analogue cameras have fewer image configuration features than digital IP cameras.
- Integration limitations – analogue systems have limited integration possibilities with other security systems, such as access control or alarm systems.
- No standalone operation – analogue cameras do not have standalone operation, they require connection to a video recorder.
- Low video resolution – traditional analogue systems operating in the PAL standard allow video recording at a maximum resolution of WD1 – 960H (960x576).
- High failure rate – analogue cable video transmission carries the risk of signal interference and numerous associated failures.
- Low security – high vulnerability to video interception as the image is not encrypted in any way, you just plug in the cable from the camera and you get the image. With a little knowledge, the image seen on the monitor side can be easily manipulated.

Traditional analogue systems are recommended to customers who do not need high quality, but only an overview image from the cameras. It is also an excellent solution for those who are looking for, an inexpensive – economical solution. In many companies, standard analogue systems are still in place. They are regularly extended and upgraded, and their users often report to us the need to adapt their existing monitoring installation to the needs of the new standard

3. SWOT analysis and company strategies

SWOT – is a popular heuristic technique for organising and analyzing information. The name is an acronym from the words for the four components of the analysis (*Strengths*, *Weaknesses*, *Opportunities* and *Threats*). While not a substitute for risk analysis, it can be seen as a preliminary element of it, particularly in cases where there is a lack of an appropriately

tailored methodology and basic parameters to perform a level III risk analysis. This may be for a specific information system or more generally for a digital processing system.

The purpose of the SWOT analysis is not only to prepare a suitable matrix table of the relationships between the above-mentioned four components of the SWOT analysis), but on the basis of this matrix, the relationships between opportunities-threats and strengths-weaknesses can be established and, consequently, a strategy can be set for the further development of the company. The SWOT analysis should be developed in a quantitative way, assigning an appropriate scale to each of the factors analysed, and it is recommended that appropriate weights are set to them.

SWOT analysis is a tool used in the process management approach to strategic planning that helps identify strengths, weaknesses, opportunities and threats. Most commonly, SWOT analysis, is used to plan a company's business strategy, but it can also be used in new marketing strategies or personal development. We very often turn to the SWOT tool when reviewing management and defining the context of the organisation, more specifically the internal and external factors relevant to the purpose and strategic direction of the organisation, as well as those that affect the organisation's ability to achieve its intended results. SWOT analysis, is also a reliable tool for risk assessment. Guidance on this aspect is provided in VDA4 – Quality Assurance in the Process Landscape, Section 2: Risk Analyses (VDA, 2020)**.**

SWOT analysis consists of dividing the information gathered about the activities and planned development strategy of a given enterprise into four groups (four categories of strategic factors):

- **S** (Strengths) – anything that represents an asset, a superiority, an advantage,
- **W** (Weaknesses) – anything that represents a weakness, a barrier, a disadvantage,
- **O** Opportunities) – anything that represents an opportunity for beneficial change,
- **T** Threats) – anything that poses a danger of adverse change.

Information that cannot be correctly categorised into any of these groups is not considered further in the analysis.

The SWOT analysis distinguishes four action strategies that a company can take: aggressive, defensive, competitive and conservative (SWOT, 2024). It all depends on which boxes on the SWOT matrix dominate the others, i.e. get the most points.

1. **Aggressive strategy** (**strengths** and **opportunities** dominate) – this is the best possible situation. This **strategy** relies on the company's strong expansion and seizing opportunities.
2. **Conservative strategy** (**strengths** and **threats** dominate) – should be considered when a company has internal potential but an unfavourable environment prevents it from growing strongly. This strategy assumes that strengths must be used to deal with external threats.

3. **Competitive strategy** (dominated by **weaknesses** and **opportunities**) – involves exploiting opportunities while eliminating the company's weaknesses. The advantage of this situation is a friendly environment that allows the company to maintain its position in the market.
4. **Defensive strategy** (**weaknesses** and **threats** dominate) – if the negative factors outweigh the positives, there is a risk of the business failing. The focus should therefore be on the survival of the organisation (e.g. merging with another company).

In order to carry out a good SWOT analysis of a company you need to:

1. The first step is to assemble a team. Define the purpose and object of the company's SWOT analysis and explain to all involved the meaning of the analysis activities – i.e. *what* we want to achieve and *why*.
2. Introduce the adopted SWOT analysis procedures to the participants. Explain *exactly* what is meant by each term and provide examples to illustrate them. Encourage people to ask questions in order to dispel any doubts at this stage.
3. Have the team members prepare a thorough description of the business and its growth prospects and develop an individual analysis of the advantages, disadvantages and opportunities and threats that they see as strategic for the company.
4. Develop a common SWOT analysis matrix and enter the factors listed by all team members there. Eliminate those that are strategically irrelevant. Prepare a glossary of basic terms – so that no one is in any doubt as to the meaning of particular terms.
5. Hold a discussion with the team on the conclusions of the analysis. To try to look at the results from different points of view. Points can be awarded to individual factors according to their importance: from -2 to 0 for *weaknesses* and *threats* and from 0 to +2 for *strengths* and *opportunities*.
6. Based on the results, develop an initial action strategy to be further refined and implemented by the company's management.

Such an analysis can also be presented graphically as a SWOT analysis diagram. The related diagram is presented at Figure 1.

SWOT	**Opportunities (O)**	**Threats (T)**
Strengths (S)	Aggressive strategy	Conservative strategy
Weaknesses (W)	Competitive strategy	Defensive strategy

Figure 1. SWOT analysis diagram.

4. Sources of information about the proposed system

During the preparatory work for the analysis of the analogue closed-circuit television system on the example of a certain nationwide organisation ABC (name of organisation changed in the paper) using the Polish standard PN-EN 62676-4 (Polska Norma, 2024). The primary sources of information about the proposed system were:

1. Interviews with system supervisors and operators.
2. Local inspections.
3. System documentation provided.

Re 1. personal sources of information:

- Information obtained from an interview with the CCTV system server administrator.
- Information obtained during a telephone conversation with an employee from the LAN management team.
- Information from an employee in the organisational unit responsible for protection of classified information.
- Information obtained as a result of an interview with the head of the unit referred to in the previous bullet point.
- Information obtained from security company personnel regarding the history of events and incidents.

Re 2. local inspections:

- Viewing at the reception of an operator station consisting of an event recorder, a keyboard together with a joystick.
- Overview of the analogue video system server administrator workstation with dedicated system management and monitoring software.

Re 3. the system documentation provided included the following documents:

- Polish standard PN_EN 62676-4 „Systemy dozoru wizyjnego stosowane w zabezpieczeniach" (en: Video surveillance systems for security applications) – Part 4: Application guidelines (Polska Norma, 2018).
- Contract between the organisation and the contractor for the maintenance of the analogue closed-circuit television system.
- As-built documentation of the modernisation of CCTV in the organisation (Dokumentacja podwykonawcza, 2013).
- DVS control keyboard user manual (DVS, 2007).
- Documentation of PSS (Professional Surveillance System) software for surveillance of small CCTV networks (Przewodnik użytkownika).
- Video recorder description and user manual – the video recorder is responsible for recording and processing the video supplied directly from the cameras via the coaxial cable (Quick start guide).

5. Detailed SWOT analysis for the closed-circuit television system

This paper assumes that the SWOT analysis will be supported at some points by a Worst Case Analysis – especially where there is insufficient information about a problem or something has not been done or has been done badly. It is a method used, for example, in issues of computational complexity of algorithms, in electronics when testing electronic circuits, and in economic issues such as portfolio management.

As written in the introductory chapter of this paper, we will now discuss the four basic categories of factors that define the SWOT analysis. We will start by identifying the components influencing the so-called strengths of the surveillance system under analysis.

Strenghts

Components shaping the strengths of the system:

S1. Experienced staff – trained security company personnel.
S2. Consulting the system operating guidelines with the head of the unit responsible for the protection of classified information.
S3. Possibility of seconding IT staff from other organisational units to operate and maintain the CCTV system.
S4. Server with practically no downtime.
S5. Maintenance contract – up to date, maintenance reports every 3 months.
S6. Dedicated CCTV surveillance server located in a guarded room.
S7. Certified malware protection standard.
S8. Zoning – III zones – use of tripods, magnetic cards, register of people entering and leaving.
S9. Due diligence in establishing monitoring modes including priorities and tracking paths.
S10. Partial compliance in some points with the Polish standard referred to in Re 3 of the previous section, e.g. for compression, export and playback of video recordings in commonly available file formats.

We now turn to an analysis of the system's weaknesses. Unfortunately, there are many more weaknesses in comparison to the strengths.

Weaknesses

Weaknesses in the system, anything that constitutes a weakness, a vulnerability in the system:

W1. No assumptions for the system – preliminary design + specifications + OR (operational requirements) – in accordance with PN-EN 62676-4[1].

W2. No information on the performance of the following tests:

- Regression – should be done after the cameras have been replaced (retrofit). Regression tests are important, as the replacement/addition of new cameras usually results in a change in the electrical operating parameters of the system – including the operating parameters of individual cameras. In order to assess the performance of individual cameras (see tests in annexes B, C, D, E of the Polish standard) after their replacement and possibly propose changes in camera settings, it is necessary to have and compare the camera specifications described in the system assumptions (OR) with the results of regression tests. It is an essential thing.
- Acceptance – in accordance with the aforementioned standard. These are *user acceptance tests (OR), and technical acceptance tests*[2].
- Technical acceptance tests according to the aforementioned standard include[3]:
  - Imaging quality.
  - Verification of image quality in terms of:
    - Contrast,
    - Colour reproduction resolutions,
  - Coherence of the imaging chain.
  - Tests of the cameras' ability to fulfil their function:
    - Inspections,
    - Recognitions,
    - Observations,
    - Detection,
    - Surveillance – event response levels and false alarm test (Annex E of the standard),
    - Identification of vehicle number plates.
    - As an option, in the event of system modifications – e.g. hardware and software localisation – factory acceptance testing (FAT) by the manufacturer is available on request.

[1] Admittedly, it is not currently mandatory for entities carrying out public tasks to use Polish standards, but this is a strong indication of the substantive correctness of the solution presented.

[2] According to §5.2 PN-EN 62676-4 of the standard – absence (OR) means the impossibility of determining whether the system meets the stated objective. In practice, this means that the standard states that it is impossible to assess the system. In this case, we cannot use the Worst Case Analysis to support the SWOT analysis, as this would mean that this study could not be carried out.

[3] Here we apply the Worst Case Analysis principle as much as possible.

- Random.
- Electrical and commissioning (Vedemecum I, 1999; Vademecum II, 2002) – in addition to taking system resistance measurements:
  - Attenuation – for both RG 6 and UTP cable.
  - Higher overtones produced by equipment such as switching power supplies, smartphone chargers and affecting the performance of the electrical network by causing non-linear distortion and power loss in three-phase receivers – transformers, capacitor banks (e.g. in UPS). Higher overtones generate interference (noise) in electrical networks especially in inductive and capacitive components – the need for appropriate filters. They are generated by IT equipment and are introduced into the installation causing overheating of the transformer windings. They are particularly dangerous for capacitor batteries (Siemek, 2002).
  - Interrogation (remote and proximity) in the section on twisted pair (Derfrer, and Freed, 2000).
  - Wave impedance for both types of cable – twisted-pair UTP and coaxial cable – is not the same as measuring resistance.
  - Grounding – surge and lightning resistance[4].
  - Signal-to-noise measurement.
- The distances to the cameras are not stated in the documentation.

W3. Some analogue cameras presented an older model – older standard – insufficient resolution – no audio recording.

W4. Lack of logical and physical separation of the CCTV system server software, especially in terms of security, from the organisation's LAN network.

W5. Scarcity of technical documentation on the system – e.g. commissioning documentation and formal acceptance document, declaration of conformity with national regulations – concerning national or international law – compliance with standards if necessary, recommendations for operation and maintenance of the system.

W6. No information on the number of system failure events – statistics – e.g. abrasion of PVC pipe cables during façade works – if any, drive failures etc.

W7. No information on further training received by security company staff beyond purchase training.

W8. No power balance for the system's cameras.

W9. No re-testing of system resistance according to maintenance rules.

W10. Lack of information on the statistics of events recorded by the system in the sense of the standard – use of the following functions:

[4] The signal grounds from all cameras should connect at the recorder, but should not connect at the camera side. Also, there should be no connection between the signal ground and the camera power ground – this is particularly important in cameras powered by 24 VAC, and not even allowed in cameras powered by 230 VAC. Active video separators are used to eliminate interference and various power supply problems.

- Inspection.
- Identification.
- Recognition.
- Detection – the archiving practically covered 28 days – it is then overwritten.

W11. The DVS keyboard software has not been updated for several years.
W12. No expansion possibility of the recorder.
W13. No formal written procedures for analogue system operators.
W14. Poor quality reporting of maintenance inspections – curtly limited to a statement of positive acceptance – see standard § 17.3 PN-EN 62676-4.
W15. Non-compliance with the Polish standard in some points of the standard's recommendations.

Threats

Hazards, anything that poses a risk, a danger of adverse change.

Threats arising:

T1. in the absence of tests carried out – the actual technical condition of the system determines the resistance of the system, especially in bad weather conditions – fog, heavy rain, snow, etc.,
T2. from the lack of formulated requirements – assumptions for the system – the lack of a path to the target point and its definition, which should be described in the chapter on the "system life and development cycle",
T3. due to the lack of formalised procedures,
T4. from the scarcity of technical documentation,
T5. from the lack of maintenance of incident statistics – inability to assess the probabilities of incidents,
T6. from the lack of logical and physical separation of the CCTV system server – the possibility of a hacking attack,
T7. resulting from the lack of periodic training, which affects routine handling of situations that require deeper analysis of incidents,
T8. lack of software updates, which reduces the efficiency of system use (server software, DVS keyboard software),
T9. from the requirements of GDPR (General Data Protection Regulation).

Opportunities

Opportunities, anything that creates a chance for positive change[5]

O1. Opportunity to upgrade the system when the organisation receives external orders – additional income from the organisation's regulations and charters (opportunity to subsidise the closed-circuit television system).

O2. Potential for additional full-time positions.

O3. Possibility of additional training related to system upgrades.

O4. Possibility of evolution of the analogue system to IP digital surveillance supervised from the technical side by a company contracted to technically maintain the closed-circuit television system.

O5. Possibility to refine and complete the documentation (formalisation of procedures) in order to manage and operate the system more efficiently.

O6. Ability to perform missing tests in order to obtain reliable information on the state of the system and make necessary changes resulting in improved system performance – especially user acceptance tests.

O7. Ability to conduct a risk analysis of the video system as recommended by the standard after receiving basic guidelines from the Information Security Management Committee/Commission of the organisation's top management for establishing the components of the risk analysis for the organisation-approved by this body, and the results of an independent audit of the system regarding e.g. good practices and probability estimates of information security management events in the ministry, and the security policies of the other 2 levels (level 1 was approved by the previous management of the organisation).

O8. Possibility of external audit of CCTV system for compliance testing.

O9. The possibility of applying for a quality certificate after improvements and expansion of the system.

O10. Ability to mobilise the system maintenance company to fulfil the scope of the contract in terms of producing more accurate reports on the maintenance work carried out.

O11. Ability to set up an event log to enable relevant statistics to be kept.

Based on the above established facts, we can now construct a matrix of relationships between the aforementioned categories of strategic factors, assuming the following conditions:

CON1. We treat the strengths and weaknesses of the system as a set of internal factors.

CON2. We treat opportunities and threats as a set of external factors.

CON3. We take the degree of dependency in the form of an impact level on the following scale:

[5] Otherwise, these are potential opportunities that may or may not be exploited, but all possible ones are considered in this case.

0 – no significant impact,
1 – weak interaction – indirect relationship,
2 – strong impact.

The 25 x 20 global dependency matrix M (Figure 2) below consists of four sub-matrices M1, M2, M3, M4 of the following dimensions:

- M1: matrix 10x11.
- M2: matrix 10x9.
- M3: matrix 15x11.
- M4: matrix 15x9.

M =

M1 (S)	M2 (T)
M3 (W)	M4 (O)

Figure 2. Global dependency matrix M and four sub-matrices M1, M2, M3, M4.

Thus, the dependency matrix M has 500 elements, which map the existing reality, i.e. the current state of analogue monitoring. Designations have been adopted here in accordance with the previously adopted notation. In particular:

- S1, S2, ..., S10 – denotes the strengths of the system – there are 10 of them – the letter S is an abbreviation for Strengths. These form part of the set of internal factors of the SWOT analysis, as per condition CON1.
- W1, W2, ..., W15 – indicates the weaknesses of the system – there are 15 of them. The letter W is an abbreviation for Weaknesses. They form part of the set of internal factors of the SWOT analysis, according to condition CON1.
- O1, O2, ..., O11 – denotes opportunities that can be exploited to improve the performance of the system – there are 11 of them. The letter O is an abbreviation for Opportunities. These form part of the SWOT analysis's set of external factors, according to the condition CON2.
- T1, T2, ..., T9 – denotes threats to the system – there are 9 of them. The letter T is an abbreviation for Threats. They form part of the SWOT analysis's set of external factors, according to condition CON2.

The scale adopted and the components of the 4 strategic category groups listed above map the current state of the system in the matrix given below. The individual values of the matrix demonstrate the extent to which the individual components of the strategic factors are related to the knowledge of the expert performing the analysis, as derived from the information sources provided, as previously outlined in chapter 2. It is inherently subjective – it can be objectified by repeating the assessment of the creation of matrix values by several other experts, calculating average values and entering them into the resulting dependency matrix in place of the previous values.

A twin method called TOWS should also be mentioned here. A SWOT analysis commences with an evaluation of the organisation's internal strengths and weaknesses. This is followed by the identification of opportunities for optimising the organisation's performance, with due consideration of the external environment. In contrast, a TOWS analysis begins with the identification of external opportunities and threats, and the subsequent analysis of the organisation's capabilities in light of these. This approach is therefore reversed to that of the SWOT method. These opportunities and threats are then contrasted with the existing conditions (strengths and weaknesses) to exploit opportunities to remove or offset threats (Bubacz, 2010).

The matrix M of relationships between sets of internal and external factors is presented in Table 1.

Table 1.
The global dependency matrix M

	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	T1	T2	T3	T4	T5	T6	T7	T8	T9
S1	0	0	1	1	2	0	1	1	1	1	2	0	0	2	1	2	0	2	2	1
S2	0	2	1	2	2	2	2	2	1	2	2	1	2	2	2	2	1	2	1	1
S3	2	0	2	2	1	2	1	0	0	0	0	0	2	1	1	0	2	1	1	0
S4	0	0	0	1	1	0	0	0	1	0	0	0	0	0	1	0	0	0	2	1
S5	1	1	1	2	2	2	1	2	2	2	1	1	1	1	2	2	1	1	1	1
S6	1	0	0	2	2	0	0	0	1	1	0	1	0	0	1	0	2	1	0	1
S7	1	0	1	1	1	1	1	1	1	0	0	1	1	2	0	2	2	1	1	1
S8	0	0	1	1	1	1	1	0	1	0	0	0	1	1	0	1	0	0	0	1
S9	1	1	1	1	1	1	1	2	2	2	1	1	2	2	1	1	1	2	1	1
S10	1	0	1	1	1	2	1	1	0	1	0	2	2	1	2	1	1	1	1	1
W1	2	1	2	2	2	2	2	2	2	1	2	2	2	2	2	1	1	2	1	2
W2	1	1	1	2	1	2	2	1	1	1	0	2	1	1	2	1	2	0	2	2
W3	2	0	0	2	1	2	0	2	1	2	0	2	1	0	1	0	0	1	1	1
W4	1	0	1	1	1	2	1	0	2	0	0	0	1	1	1	1	2	1	0	0
W5	1	1	1	1	2	2	1	1	1	1	0	1	2	0	1	0	1	1	1	2
W6	1	0	0	0	1	1	1	1	1	1	1	1	1	2	1	2	2	1	1	0
W7	1	0	2	0	2	1	0	0	1	1	0	1	1	1	0	1	1	2	1	1
W8	0	0	0	1	2	2	1	1	1	0	0	2	2	1	1	0	0	1	0	0
W9	1	0	0	0	1	2	1	1	1	2	0	2	0	1	1	0	0	0	0	0
W10	2	0	1	1	2	2	2	2	2	1	1	2	2	2	1	1	0	1	0	2
W11	1	0	2	1	2	2	1	1	2	2	0	1	2	1	1	0	1	2	2	0
W12	2	0	2	2	0	1	2	0	2	0	1	1	2	0	0	1	0	1	0	1
W13	1	1	1	1	2	1	1	2	1	2	2	2	2	2	2	2	2	2	2	2
W14	2	1	1	1	2	2	2	2	2	2	0	2	2	1	2	0	2	0	0	1
W15	1	1	1	1	2	2	2	2	2	1	1	1	2	1	2	1	1	2	2	2

In the dependency matrix M presented in Table 1, we can distinguish four sub-matrices M1, M2, M3, M4 representing four different behavioural strategies:

- M1 (SxO) – proposes an aggressive strategy to solve the problem,
- M2 (SxT)– suggests a cautious behavioural strategy (conservative strategy),
- M3 (WxO) – proposes a strategy for addressing vulnerabilities in a stable external environment,
- M4 (WxT) – represents a defensive behaviour strategy called survival technique in SWOT analysis.

6. The concluding remarks of the SWOT analysis

The four fundamental sub-matrices of the primary dependency matrix, as previously outlined, can be employed to ascertain definitive conclusions regarding the optimal trajectory for the evolution of analogue video within an organisational context.

By taking into account the threats and weaknesses of the system (as defined in risk analysis terminology), the SWOT analysis enables the selection of an appropriate strategy to address the identified issues. It should be noted that the proposed approach does not replace the necessity for risk analysis, as previously mentioned at the outset of this paper. Rather, it can be viewed as a preliminary element of the risk analysis process.

Analysing the four sub-matrices M1, M2, M3, M4, we can see that the weight of a sub-matrix as the sum of all the values of its elements (counting by rows or columns) is for:

- sub-matrix M1 – 102.
- sub-matrix M2 – 92.
- sub-matrix M3 – 189.
- sub-matrix M4 – 151.

The above results can easily be checked using a simple sum function in MS Excel. Note that max {102, 92, 189, 151} = 189 , which suggests that :

1. In the system in question, efforts should first be concentrated on the task of eliminating the weaknesses of this system, which requires little investment, and is in line with the interpretation of the sub-matrix M3 with a weight of 165. These weaknesses have already been pointed out previously. The nature of this organisation is such that it operates in a fairly stable external environment and does not have to compete on it.
2. Next in line (according to the decreasing value of the weights) is sub-matrix M4 with a weight of 151 indicating a defensive strategy, i.e. a survival strategy (not making any changes to the system), which in my opinion should be firmly rejected if we want to develop the system or improve its performance.
3. The next most desirable option is the sub-matrix M1 with a weight of 102, which suggests the possibility of making a larger investment in the system – this is an aggressive strategy, i.e. the possibility of making larger modifications to the system, e.g. moving to a digital surveillance system with IP cameras, provided sufficient funding is available.
4. Finally, the least interesting option from the point of view of this case study is option 2 – the sub-matrix M2 (weighting 92), as it suggests as a solution a conservative strategy – little investment in technological innovations, in modern means of advertising, cautious development of the system based mainly on own savings – little use of credit lines.

7. Conclusion

The SWOT analysis is an essential tool in the process approach of business management for assessing the current situation of a company and determining key operating strategies (SWOT, 2024). SWOT helps to better understand the events surrounding a company and its effective use of results, allows for the construction of sound business strategies, adaptation to market changes and long-term success. It is not only a diagnostic tool, but also the foundation for making wise strategic decisions that lead to the sustainable development of the organisation.

It should be borne in mind that if the method of action presented in the paper is chosen, we should consider the main strategic objectives in the chosen company at all times**.** Sometimes the choice of a particular strategy is more complicated and depends on a particular combination of factors. Of course, SWOT analysis also has disadvantages. Above all, it is prone to subjectivity and its results are often obvious or lead to misinterpretations. Besides, not all relevant factors for a company can be encapsulated in terms of advantages, disadvantages, opportunities and threats.

All this means that this method, although popular, in practice can often be **questioned**. Thus, if we are interested in meaningful results, the SWOT analysis can be taken as a starting point for further assessment of the strategic situation of the company. This will be facilitated by a number of factors, including:

- ASTRA analysis.
- PEST analysis.
- Porter's five forces concept.
- Scenarios of ambient conditions.
- Scenarios of possible events.
- Simulation scenarios.

Surveillance systems are highly valued in many companies, institutions, shops. Their main aim is to increase the level of security. Nowadays, the concept of CCTV has been replaced by closed-circuit television. Initially, CCTV cameras with all their equipment were mainly installed in industrial facilities for the surveillance of a particular building and the area around it. At the time, their aim was to prevent theft and minor offences by company employees.

Basically, we can divide closed-circuit television systems into: IP digital (network) monitoring, analogue monitoring – traditional, hybrid monitoring – is a combination of both technologies in one system. As the consumer society develops, closed-circuit television systems are mainly installed in public places such as parks, banks, restaurants, hypermarkets, residential buildings, guarded car parks, railway stations and main city streets.

Nowadays, it is possible to observe an increasing interest and demand for closed-circuit television systems due to the miniaturisation of cameras and all instrumentation. The solution presented in the example company "ABC" can be used as a starting point for further assessment of the companies' strategic situation.

Due to the ever-widening applications and growing demand for closed-circuit television, security system manufacturers continue to constantly improve the intelligent capabilities of cameras. Modern cameras can, among other things (Gaździcki, 2024):

- identify the object in the recording as a person or a vehicle,
- count persons or length of stay,
- detect left luggage,
- recognise suspicious behaviour and gatherings,
- recognise persons entering, leaving and passing through a marked line,
- detect the number of people in a queue,
- capture images of faces,
- determine a person's approximate age, gender, colour of clothing, facial expressions or additional items of clothing e.g. backpack, helmet or mask,
- identify features e.g. facial hair, glasses or headgear,
- detect burglary,
- detect scene changes,
- identify video sabotage,
- detect loss of focus,
- carry out vehicle detection,
- detect vehicle parking,
- recognise license plates (LPR),
- recognise the colour and model of the vehicle,
- track vehicles or people (PTZ cameras),
- thermal imaging fire warning,
- measure the temperature of the human body or objects.

Analogue monitoring works on the basis of the well-known analogue technology. In a nutshell, it is a set of devices that produce or mediate an analogue signal that allows analogue recording by rendering frequency and intensity in the form of an image, sound or text. Today, modern analogue monitoring is not really analogue – it is just a word for describing the system. Often, the only all-analogue component included is a coaxial cable with a combined power cable.

As in almost every industry, analogue technology is being displaced by digital technology so in the closed-circuit television industry, analogue monitoring is increasingly being displaced by digital (network) IP monitoring.

Modern systems use wireless connections and digital cameras, which can have much more functionality. What is more, a CCTV system designed with digital technology does not require cameras to be connected to a video recorder, as the image can be received remotely on mobile devices and computers using an internet connection. However, modern digital recorders allow camera images to be saved as a video on a hard drive or server.

Finally, it should be noted that there are cases of companies that, despite their previous assumptions, do not commit to such a development strategy at all.

References

1. Bubacz, K. (Ed.) (2010). *Zarządzanie strategiczne. Metody analizy strategicznej z przykładami.* Poznań: Wydawnictwo Politechniki Poznańskiej.
2. Derfler, F., Freed, L. (2000). *Okablowanie sieciowe w praktyce.* Gliwice: Helion.
3. *Dokumentacja Powykonawcza Modernizacji Monitoringu TV Przemysłowej w organizacji* (2013). Warszawa: BRABORK Laboratorium Sp. z o.o.
4. *DVS control keyboard, user manual* (from the hardware manufacturer), 5.10.2007.
5. Gaździcki, M. (2024). *CCTV – Co to? Czym jest monitoring CCTV?* Retrieved from: https://solidsecurity.pl/blog/cctv-co-to-czym-jest-monitoring-cctv, 10.10.2024.
6. Kabzińska, J., Szafrańska, M. (2018). Zasady ewaluacji skuteczności monitoringu wizyjnego. *Przegląd Policyjny, vol. 4, no. 132*.
7. Polska Norma [Polish standard] PN-EN 62676-4. *Systemy dozoru wizyjnego stosowane w zabezpieczeniach, Część 4, Wytyczne stosowania* (2018). Warszawa: PKN (Polski Komitet Normalizacyjny).
8. *Quick start guide for the video recorder* – pdf file on CD (from the hardware manufacturer).
9. Siemek, S. (2002). *Instalacje elektryczne dla zasilania urządzeń elektronicznych.* Warszawa: Centralny Ośrodek Szkolenia i Wydawnictw SEP.
10. *SWOT – Narzędzie planowania strategii biznesowej i analizy ryzyka* (2024). Retrieved from: https://akademiajakosci.com/swot-narzedzie-planowania-strategii-biznesowej-i-analizy-ryzyka/, 10.10.2024.
11. User guide. *Professional Surveillance System, ver. 4.06, pdf file* (from the hardware manufacturer).
12. *Vademecum Teleinformatyka I.* Praca zbiorowa (1999). Warszawa: IDG Poland S.A.
13. *Vademecum Teleinformatyka II.* Praca zbiorowa (2002). Warszawa: IDG Poland S.A.
14. VDA 4 – *Quality Assurance in the Process Landscape*. Sections 1–4. (EN). VDA4 – Quality Assurance in the Process Landscape, Sections 1-4: General, Risk Analysis, Methods, Process Models. 3rd edition, fully revised and updated, August 2020.

SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

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WELL-BEING OF MICRO-ENTERPRISE ENTREPRENEURS FROM THE SILESIAN VOIVODESHIP DURING AN UNSTABLE ECONOMIC SITUATION

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Purpose: The aim of the paper is to analyze a selected issue from the problem of the adverse impact of external factors on the functioning of microenterprises, in order to develop forms of assistance. The article focuses on the subjective feelings of micro-entrepreneurs in relation to the difficulties of running a business during the pandemic and during the unstable economic situation.
Design / methodology / approach: The analysis included subjective feelings of 271 micro-entrepreneurs from the Silesian Voivodeship. Micro-entrepreneurs are people of different ages, with different experience in running a micro-enterprise. The research sample includes over 100 professions. The research method used was an interview and a survey, and the research tool was a form.
Findings: Micro-entrepreneurs, due to their age, experience, flexibility in changing industries, number of employees, family obligations, react differently to factors that are unfavourable for running a business. These factors mean that the condition of the micro-enterprises studied is not uniform. The conducted research is part of a larger analysis aimed at identifying the relationship between various external factors and the psycho-physical conditions of micro-entrepreneurs, in order to develop solutions that support the activities of micro-entrepreneurs.
Research limitations/implications: Identifying factors that may lead to discontinuation of business activity in an economically unstable situation may contribute to the development of forms of assistance for micro-entrepreneurs.
Originality / value: The negative impact of the 2019 global pandemic has greatly affected micro-enterprises. The military conflict in Ukraine in early 2022 has destabilised global economy. Rising inflation in Poland became even more pronounced after the outbreak of war. Many micro-enterprises faced a difficult situation. It is important to gain knowledge about the impact of constraints related to the economic situation on the operation of micro-enterprises in order to develop mechanisms to mitigate negative effects on entrepreneurship based on micro-enterprises.
Keywords: micro-enterprises, unstable economic situation, well-being.
Category of the paper: Research paper.

1. Introduction

In the years 2021-2024, 271 microenterprises operating in the Silesian Voivodeship were examined. The impact of external factors of the pandemic period on the functioning of these entities was analyzed (Michalski, 2022), and then examined the impact of the next two years with the global economy destabilized by the war in Ukraine (Michalski, 2023). Further research conducted among micro-entrepreneurs allowed for the collection of further data. The research also took into account internal aspects of micro-enterprises, such as experience, economic experience, methods of financing the activity, ability to use aid funds and individual feelings related to difficulties resulting from the economic situation. This paper focuses on the individual feelings of entrepreneurs related to the impact of the pandemic and the economic situation.

2. Functioning of micro-enterprises during an unstable economic situation

Micro-enterprises are entities conducting business activity and employing several (up to nine) people during the year, and their annual revenue does not exceed EUR 2 million during the tax year. The value of the euro in relation to the PLN is determined according to the NBP exchange rates. Micro-enterprises also include sole proprietorships. For them, the annual revenue threshold is set at 1.2 million EUR (Nawrocki, 2022; Smolarek, 2015). Micro-enterprises often base their functioning on cooperation with larger enterprises.

The period of the coronavirus pandemic in 2019-2022 and then the armed Russia attack against Ukraine affected many areas of human functioning, including running a business. The period of 2019-2022 was associated with strong restrictions, largely concerning the mobility of human and material resources, which adversely affected the condition of microenterprises. On the other hand, the war in Ukraine caused, among other things, an energy crisis, which manifested itself in high prices of energy media. This increased the operating costs of enterprises, including micro-entrepreneurs. In addition, the decline in real household income at that time resulted in an outflow of customers from enterprises (Senderowicz, 2023; Machniewski, 2023; Możdżanowska). The number of microenterprises in the Silesian Voivodeship at the end of 2022 decreased compared to the situation in the same period of 2021. At the end of 2022, 245 793 microenterprises were registered in the Silesian Voivodeship, employing a total of 507 266 people (GUS, 2023). A year earlier, the number of registered entities was 256,888, while the number of people employed in these companies was 501 693 (GUS, 2022).

Inflation, which affects the economy in both micro- and macroeconomic terms, means that at its high level, effective cost management by micro-entrepreneurs can become a very difficult task (Olszowy, 2024).

3. Characteristics of the selected research sample, research methods and tools used

The analysis of the impact of specific external factors on the well-being of micro-entrepreneurs was based on two groups of data. The first one is data obtained in 2020-2022 from 132 micro-entrepreneurs. Part of this data was used for analyses described in two articles (Michalski, 2022, 2023), which discussed the condition of microenterprises during the pandemic period and then during the economic instability caused by the war in Ukraine.

The second set of data is information obtained from 139 micro-entrepreneurs in the period from 2023 to mid-2024. Among the 139 examined were 64 micro-enterprises, examined earlier, in the years 2020-2022. The repeated examination of these entities was aimed at conducting a random check of the state of these micro-enterprises, already operating in a much more stable economic situation.

In total, 271 micro-entrepreneurs were surveyed, representing over a hundred professions related to production or trade. Below is a list of professions and the number of micro-entrepreneurs practicing them: IT services (computer graphics, image and sound digitization, visual identification design, website design,) – (10), advertising activities (advertising studio, design and production of advertising banners) – (2), photographic service and services – (3), spring winding – (1), gardening services and sale of plants, florist services – (8), sale of food and industrial products – (6), emptying of basements and attics – (3), production and sale of bakery and confectionery products – (5), carpentry services – (4), construction, renovation, masonry, painting and finishing services, paving, electrical, roofing, tiling – (37), car or motorcycle repair shop, bodywork and painting services – (28), cosmetic and hairdressing services, tattoo studio – (19), tailoring – (4), catering services – (11), repair of electronic equipment – (8), tire service – (8), architectural services and interior design – (4), antique and antiquarian book and music shop – (6), production and sale of ornamental and decorative products – (6), printing and large-format printing, printing and embroidery on clothing – (8), artistic painting and sculpture, engraving – (5), sale of car parts and batteries – (5), installation and cleaning of air conditioning – (2), production of water filters and filling of cartridges with compressed CO_2 – (2), installation of furnaces and underfloor heating – (3), water and sewage services – (4), sale of music records – (2), translation, accounting services, assistance in settlements – (4), upholstery, leatherwork, saddlery and shoemaking services – (5), carpet cleaning, apartment cleaning – (3), repair of cameras and repair of audio equipment – (2),

production of sheet metal garages and production of wooden elements, production of metal and wooden elements – (5), welding of ferrous and non-ferrous metals – (1), geodetic and cartographic services – (3), drilling deep wells – (1), demolition of buildings – (1), sale of locks, key duplication, programming of remote controls – (3), jewellery repair – (1), trade in metal goods – (1), framing workshop – (1), sale of articles for artists – (1), production of mosquito nets – (1), installation of roller blinds – (1), bookbinding workshop – (1), rental of carnival costumes – (1), artistic blacksmithing – (1), installation of fireplaces – (1), sale of herbal and medicinal articles – (1), furniture renovation – (1), car repair service – (1), sale of health and safety and fire protection equipment – (2), first aid training – (1), service of household appliances – (1), installation of gates and fences – (1), bicycle and snowboard service – (3), installation of cash registers – (1), scrapping of vehicles – (1), trade in second-hand clothing and textiles, sale of haberdashery – (3), photovoltaic installation – (2), production and sale of ecological preserves – (2), animation activities for children – (1), construction scaffolding rental – (2), height services – (1), watchmaking services and battery replacement – (1), production of packaging from various materials – (3), stonemason's workshop – (2), funeral services – (2), production and sale of office supplies (1) .

The research method used was an interview and a survey, and the research tool was a form.

4. Discussion

Issues related to well-being included topics such as: a sense of uncertainty about one's own well-being and the well-being of one's closest relatives, concern for co-workers, the impact of isolation on well-being, family relationships, but also on the possibility of running a business.

The micro-entrepreneurs surveyed reacted in different ways to the unfavorable factors related to the pandemic and the unstable economic situation. These reactions were related to the personal psycho-physical predispositions of the business owners, age, experience, a sense of burdensome responsibility for family and colleagues, the possibility of obtaining alternative income, awareness of the possibilities of using external help, etc.

Figure 1 shows age structure of microenterprise owners.

There were no entrepreneurs under 20 among the entities surveyed. In terms of numbers, people over 40 dominated (144 people). There were 70 entrepreneurs between 31 and 40 among the surveyed. The last group consists of people aged 21 to 30. There were 57 of these entrepreneurs among the surveyed.

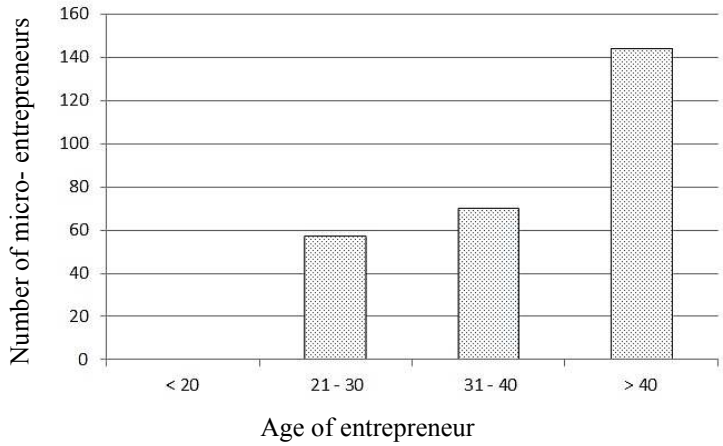

Figure 1. Age structure of microenterprise owners.

Source: Own elaboration.

An important factor that determines the well-being of the owner of a microenterprise, in a difficult period for functioning, is the responsibility for the well-being of the employed employees. Microenterprises, apart from the owner, employ up to 9 employees. The respondents are the only employees of a one-person microenterprise, or they employ from 1 to 7 people. There were no entrepreneurs who employed 8 or 9 employees in the study group. The number of employees is presented in Figure 2.

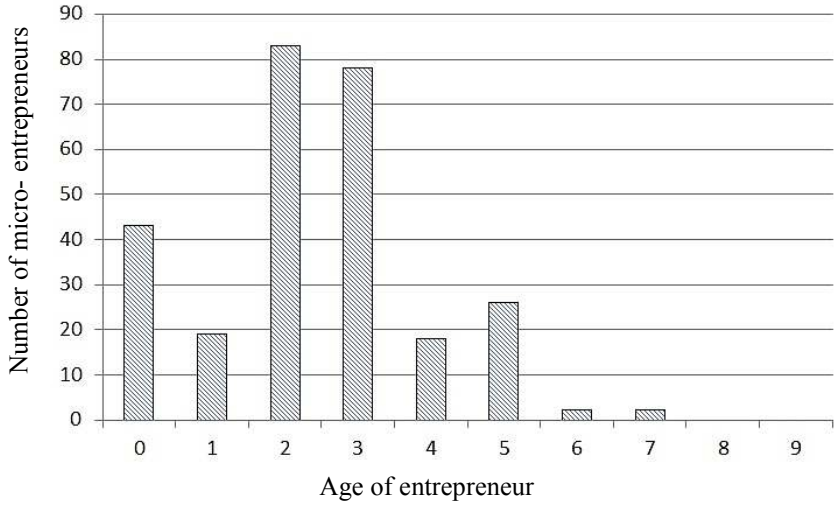

Figure 2. Number of employees employed by entrepreneurs.

Source: Own elaboration.

Among the 271 entrepreneurs surveyed, 41 are micro-entrepreneurs running one-person businesses. 19 owners employ one employee. The majority were owners employing 2 and 3 employees. And so, respectively – 2 employees are employed by 83 micro-entrepreneurs, while 3 – 78. 4 employees are employed by 18 of the surveyed, 5 – 26, while 2 owners employ 6 and 7 co-workers.

The experience of the surveyed entrepreneurs also varies. It shows Figure 3.

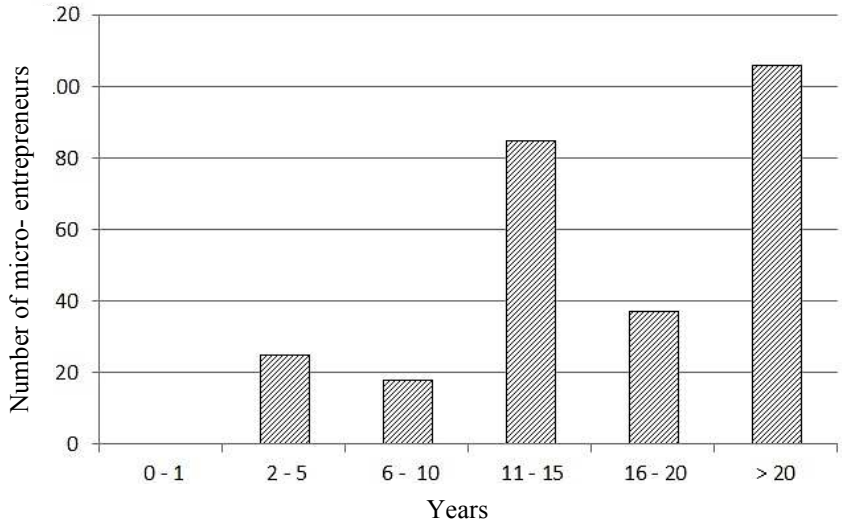

Figure 3. Length of operation in the market of the surveyed entities.

Source: Own elaboration.

Figure 4 to Figure 11 shows the subjective impression was regarding the impact of the pandemic on the microenterprise and on the quality of life of employees.

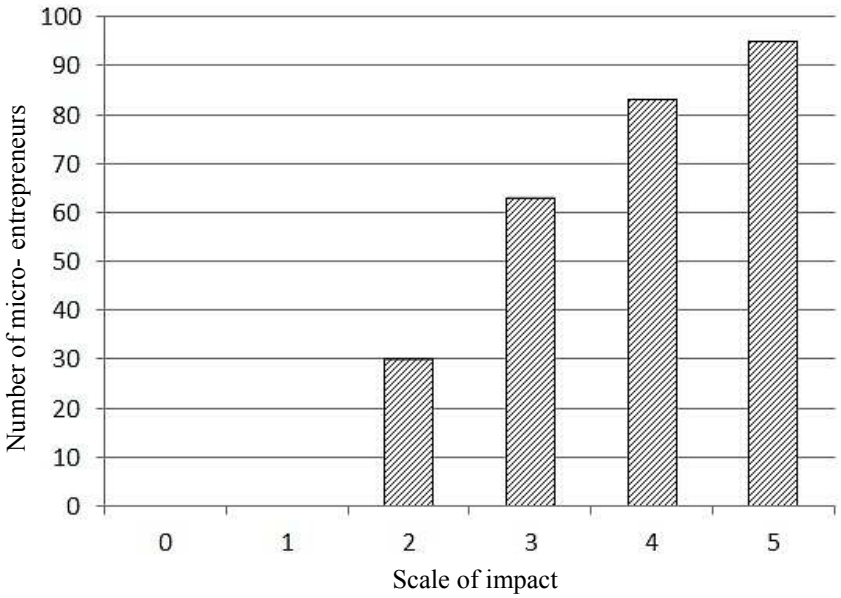

Figure 4. Feeling uncertain about one's own existence (0–5 scale of impact: 0 no impact, 5 major adverse impact).

Source: Own elaboration.

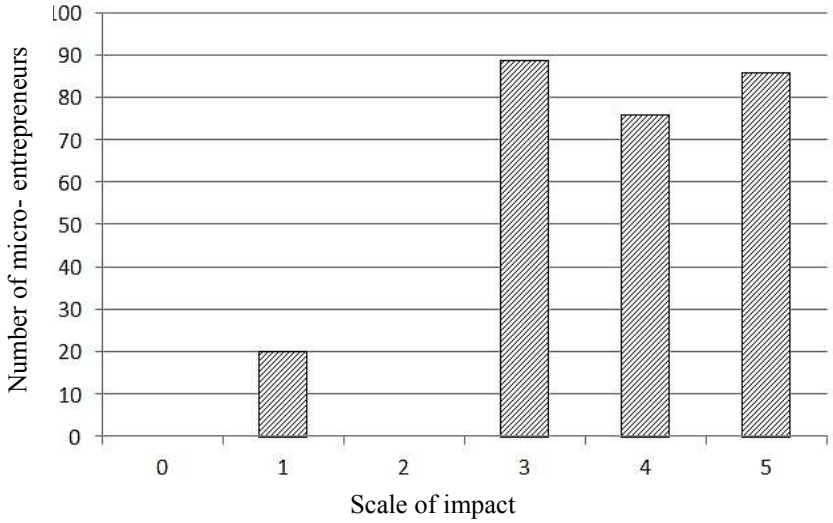

Figure 5. Feeling uncertain about the family's existence (0–5 scale of impact: 0 no impact, 5 major adverse impact).

Source: Own elaboration.

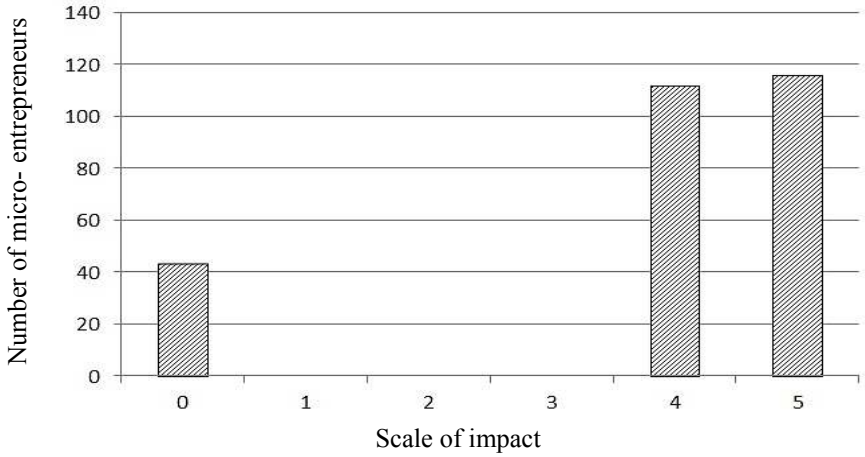

Figure 6. Concern for the fate of employees (0-5 scale of impact: 0 no impact, 5 major adverse impact).

Source: Own elaboration.

The negative feelings resulting from uncertainty about one's own existence and that of one's loved ones were shown by answers on a scale from 2 to 5. The issue related to concern for the fate of employees is slightly different. 43 of the surveyed entrepreneurs run a sole proprietorship, and the problem of concern for other employees did not concern them.

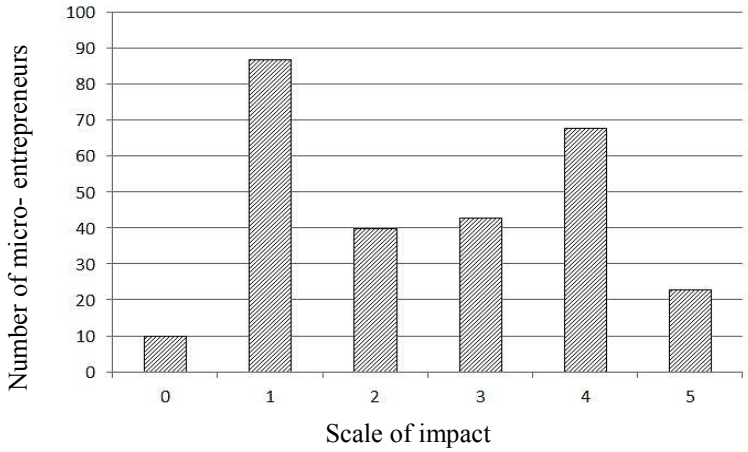

Figure 7. Feeling of lack of a government plan to counter the pandemic (0-5 scale of impact: 0 no impact, 5 major adverse impact).

Source: Own elaboration.

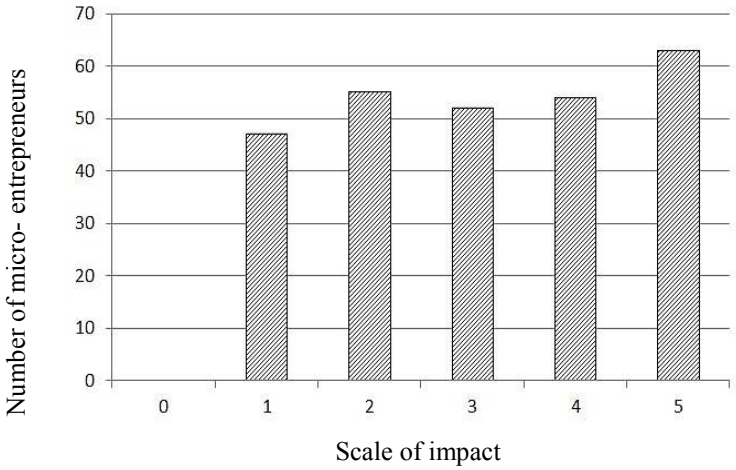

Figure 8. Inability of moving around the area (0-5 scale of impact: 0 no impact, 5 major adverse impact).

Source: Own elaboration.

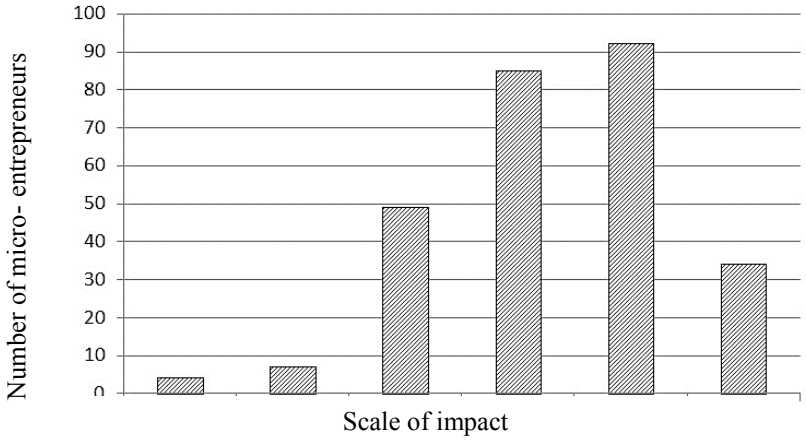

Figure 9. The impact of isolation on family relationships (0-5 scale of impact: 0 no impact, 5 major adverse impact).

Source: Own elaboration.

Figure 10 and Figure 11 shows the structure of answers to questions related to the fear of losing existing customers and even inability to continue running a micro-enterprise and the need to terminate the business.

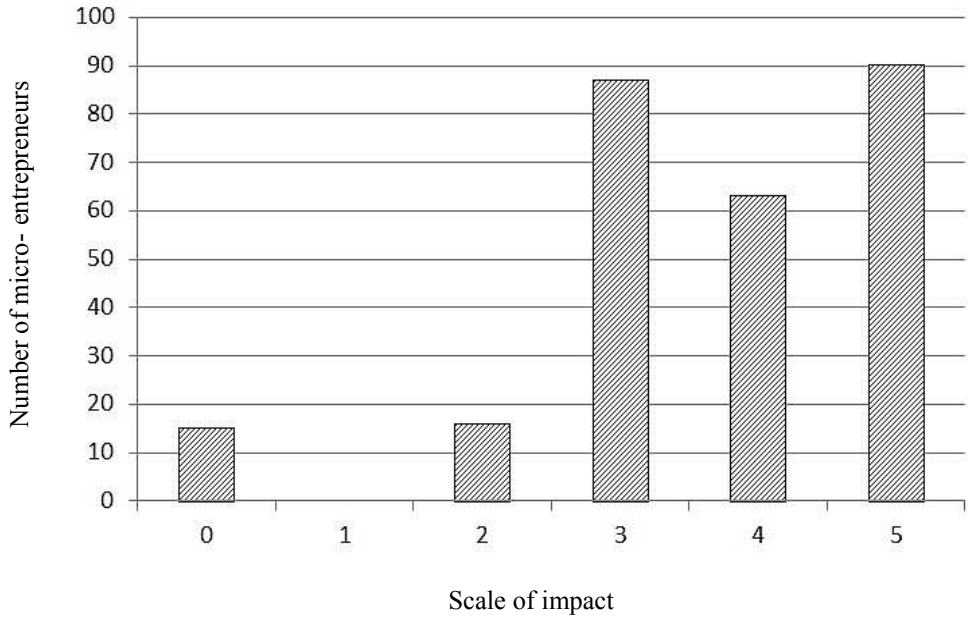

Figure 10. Fear of losing customers (0-5 scale of impact: 0 no impact, 5 major adverse impact).
Source: Own elaboration.

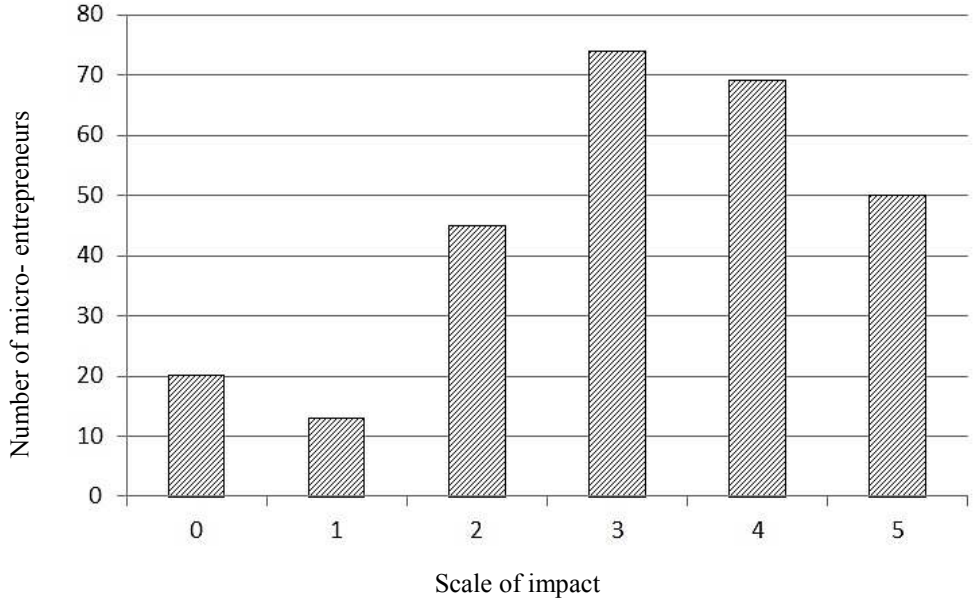

Figure 10. Fear of having to close down a business (0–5 scale of impact: 0 no impact, 5 major adverse impact).

Source: Own elaboration.

The impact of an unstable economy in 2022-23 on the well-being of microentrepreneurs is presented in Table 1.

Table 1.
The structure of responses to questions regarding the degree of impact of the unstable economy in 2022-23 on the well-being of microentrepreneurs

Analyzed aspect	The surveyed entrepreneur's answers (responses are expressed on a 0-5 scale, where 0 - no impact, 5 - large, negative impact)					
	Scale of impact					
	0	**1**	**2**	**3**	**4**	**5**
Feeling uncertain about the future of the microenterprise	0	7	18	77	80	89
Fear of having to change profession	5	14	0	0	112	140
Employees' expectations for salary increase	41	0	0	78	80	72
Fear of having to use promotions	18	58	82	55	18	40
Feeling uncertain due to the need to find new distribution channels	4	7	0	0	140	120
Feeling uncertain about having to lower prices to be competitive	4	7	49	85	92	34
Feeling uncertain due to the need to implement innovative technologies in order to become more competitive	30	25	46	73	67	30
Feeling uncertain due to fewer customers	15	0	16	87	63	90

Source: Own elaboration.

246 entrepreneurs expressed medium, high or very high concern about the fate of their company. Among the entrepreneurs, over 140 owners are over 40 years old, and about 100 micro-enterprises have been operating for over 20 years. People in this age group, who have been in the same type of business for many years, are less likely to change the industry. This is due to habits and experience gained in a profession they have been in for a long time. This group of micro-entrepreneurs is also reluctant to use solutions that are new to them, such as searching for new methods of distribution. 41 entrepreneurs work in sole proprietorships. Therefore, the issue of increasing the salaries of their employees does not concern them.

5. Summary

Due to the relatively small research sample, the obtained study results cannot be generalised and treated as a picture of the condition of all micro-enterprises in the Silesian Voivodeship. Further studies, based on a larger research sample, would provide a more comprehensive picture. However, the data collected so far allows us to conclude that entrepreneurs respond in different ways to the difficult situation their micro-enterprises faced after the pandemic and during the following months of 2022. This depends on a number of factors, such as the number of years the company has existed in the market, the degree of specialisation in the area served, flexibility in re-branding (which also depends on the number of employees in the company and their individual predisposition to accept change), or the ability to acquire external financial and non-financial support. These factors make the condition of the micro-enterprises studied not homogeneous. Researching the relationships between various factors related to the company's activities will be the next stage of work on this topic.

References

1. Cmel, P.R. (Ed.) (2024). *Działalność przedsiębiorstw o liczbie pracujących do 9 osób w 2022 roku*. Retrieved from: https://stat.gov.pl/, 5.09.2024.
2. Cmel, P.R., Płatek, A. (2022). (Eds.), *Działalność przedsiębiorstw o liczbie pracujących do 9 osób w 2021 roku*. Retrieved from: https://stat.gov.pl/, 04.09.2024.
3. Machniewski, S. *Jaki wpływ na gospodarkę Polski ma wojna w Ukrainie?* Retrieved from: https://www.money.pl/gospodarka/jaki-wplyw-na-gospodarke-polski-ma-wojna-w-ukrainie-6777226370452128a.html, 16.02.2023.
4. Michalski, K. (2022). Study of the impact of the pandemic on the functioning of micro-enterprises in the Silesian voivodeship. *Zeszyty Naukowe Politechniki Śląskiej, Organizacja i Zarządzanie, No. 161*, pp. 121-136, doi:10.29119/1641-3466.2020.148.34.
5. Michalski, K. (2023). Study on the condition of selected micro-enterprises in the Silesian voivodeship in the second half of 2022. *Zeszyty Naukowe Politechniki Śląskiej, Organizacja i Zarządzanie, No. 161*, pp. 121-136, doi:10.29119/1641-3466.2020.148.34.
6. Możdżanowska, A. *Fundusz Europejskie dla małych i średnich firm*. Retrieved from: https://www.funduszeeuropejskie.gov.pl/media/59788/ulotka-fundusze-europejskie-dla-MSP.pdf, 12.10.2024.
7. Nawrocki, A. (2022 – publikacja aktualizowana 2023). *Mikroprzedsiębiorstwo – na czym polega ten rodzaj działalności?* Retrieved from: https://magazynprzedsiebiorcy.pl/ /mikroprzedsiebiorstwo?utm_content=cmp-true, 23.07.2024.
8. Olszowy, J., Jabłoński, Ł. (2024). Wpływ inflacji na sektor MŚP. In: J. Olszowy, Ł. Jabłońki (Eds.), *Transformacja finansów i ekonomii: wyzwania i szanse*. Łódź: Wydawnictwo Naukowe Archaegraph.
9. Senderowicz, A. (2023). *Mikroprzedsiębiorstwa 2023*. Retrieved from: https://centrumanaliz.pkobp.pl/analizy-sektorowe/mikroprzedsiebiorstwa-2023, 04.09.2024.
10. Smolarek, M. (2015). Wybrane aspekty rozwoju małych i średnich przedsiębiorstw. *Zeszyty Naukowe Wyższej Szkoły Humanitas, Zarządzanie, 3*, pp. 23-38.
11. *Tarcza solidarnościowa – wsparcie odbiorców energii elektrycznej w 2023*. Retrieved from: https://www.gov.pl/web/chronimyrodziny/rzadowa-tarcza-solidarnosciowa, 10.11.2024.

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PROPOSAL FOR TOOL TO EVALUATE INDUSTRY 4.0 DRIVERS AND BARRIERS

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Purpose: The objective of this paper is to present the process of developing a research tool designed to evaluate the enablers and obstacles to the adoption of Industry 4.0, with a particular emphasis on small and medium-sized enterprises (SMEs) in Poland's automotive sector.
Design/methodology/approach: The study employs an extensive review and analysis of relevant literature, emphasizing Industry 4.0 implementation dimensions, maturity frameworks, and readiness evaluation models. A structured survey tool and a proposed framework for result visualization are developed to analyze drivers and barriers within specific functional domains.
Findings: The developed research instrument will enable prioritization of the identified enablers and obstacles to Industry 4.0 adoption based on their influence across various implementation dimensions. Visualization of the outcomes will reveal both the current state and target goals of organizations, providing actionable insights for development.
Research limitations/implications: The study is constrained by the subjective selection of functional domains and the number of Industry 4.0 dimensions considered. Pilot tests are expected to refine the methodology and provide further clarity and enhancements.
Practical implications: The insights derived from this research will offer tangible benefits to SMEs by identifying actionable strategies to address challenges and maximize opportunities in Industry 4.0 transformation. These findings can support effective decision-making and planning for digitalization initiatives in the automotive sector.
Originality/value: This research introduces a unique perspective by integrating the factors of location, sector, and enterprise size in the analysis of Industry 4.0 adoption. The proposed visualization approach and tailored research instrument provide significant value, especially for SMEs in the automotive field.
Keywords: Industry 4.0, Research tool, Performance, Drivers, Barriers, Solutions.
Category of the paper: Empirical research results.

1. Introduction

Recent research (Veile et al., 2020) shows that the latest technological developments in Industry 4.0 are reshaping future processes and interactions between stakeholders. Changes influence social, environmental, and technological aspects of our activities. Two phenomena which are Industry 4.0 and Sustainable Development can address some of the biggest issues we face as a global community, but at the same time can be a driving force for local actions within a company. Much of the work in this area concerns corporate social responsibility and the use of modern technology, for example to reduce a company's carbon footprint or implement energy transition. These two dimensions have been taken as an example to present the results of the following study.

Implementing modern technology is often a solution to the difficulty of finding employees with the right competencies. It can be a response to a lack of resources or the needs to improve operational efficiency. However, implementing Industry 4.0 solutions requires the right approach, preparation, and resources (Hilkenmeier et al., 2021). What is more, "organizational culture can affect employees' attitude towards change" (Michna, Kmieciak, 2020). Each case of implementing a new Industry 4.0 technology has specific driving forces as well as many barriers and obstacles that need to be addressed and skillfully managed in each of the functional areas of organizations. The subject literature (Horvat et al., 2018; Kiel et al., 2017; Müller et al., 2018) addresses the implementation of Industry 4.0 in specific economic conditions, e.g. developing economies, in specific economic sectors, e.g. production enterprises, as well as in organizations varying in size, e.g. large enterprises or small and medium-sized enterprises. The literature research carried out identified a research gap, the filling of which is the aim of the planned research, namely the combination of all the factors mentioned: location of the enterprises, sector of activity, and size of the enterprise. Therefore, the research subject were small and medium-sized production organizations operating in the automotive sector in Poland. These companies are mainly suppliers of materials and components.

This study aims to present and discuss the developed research tool which will be used to explore this specific interaction between the driving forces & barriers, and Industry 4.0 dimensions in functional areas of small and medium-sized enterprises. The presented results are a continuation of recent studies on maturity models, barriers and drivers in Industry 4.0 implementation and dimensions in functional areas of manufacturing organizations (Michna et al., 2021; Michna, Kruszewska, 2020, 2021, 2022).

2. Driving forces and barriers

Firstly, driving forces and barriers were identified from the literature research (Bajic et al., 2021; Grabowska, 2021; Horváth, Szabó, 2019; Karamitsos et al., 2010; Kiel et al., 2017; Michna et al., 2021; Müller, 2018, 2019; Stentoft et al., 2019; Türkeş et al., 2019; Veile et al., 2019; Vuksanović Herceg et al., 2020). The raw list includes, on the one hand, the factors influencing the decision to implement Industry 4.0 solutions as well as the reasons why organizations decide to change or adopt a new technology, and, on the other hand, a list of obstacles that block or hinder the implementation of changes. In many cases, a given driving force can also act as an inhibiting factor, such as "Lack of qualified work force" or "Finance". The raw list of barriers and drivers follows the PESTEL breakdown into political, social, environmental, technological, economic and legal factors. Table 1 presents the results for driving forces and Table 2 for barriers.

Table 1.
Driving forces for Industry 4.0 implementation

Group	Drivers from literature sources:				
	(Müller et al., 2018)	(Stentoft et al., 2019)	(Horváth, Szabó, 2019)	(Vuksanovic Herceg et al., 2020)	(Kiel et al., 2017)
P – Political	• New business models • New product offerings • Increased competitiveness	• A deliberate strategy for Industry 4.0 • Cost reduction • Improved time-to-market • Implementation of Industry 4.0 by competitors • Initiation of work in cooperation with public advisory systems	• Growing competition • Increased innovation capacity • Opportunity for business model innovation • Market competition • Increasing pressure from competitors • Tracking market trends • Demand for greater control (from top management) • Continuous monitoring of company performance	• Competitiveness • Business model innovation	• Novel business models • Competitiveness • Expansion and protection of market shares • Innovative offerings
E – Economical	• Increasing efficiency • Decreasing costs • Higher quality • Increasing speed • Increasing flexibility • Load balancing • Stock reduction		• Increasing productivity • Financial and performance factors • Reducing costs, e.g. human resources, inventory management, and operating costs • Reducing the error rate • Improving lead times (compliance with market conditions) • Improving efficiency • Ensuring reliable operation (e.g. less downtime) • Financial resources and profitability	• Cost reduction • Performance improvement	• Finance • Growing sales volumes • Several cost reduction potentials • Shorter set-up and lead times • Faster machine speed • Facilitate faster and more flexible response to customer demands • Decrease of time-to-market • Reduction of non-value-adding activities and time

Cont. table 1.

S – Social	• Reduction of monotonous work • Age-appropriate workplaces	• Lack of qualified work force	• Support for management activities • Increasing labor shortages • Reducing human work • Allocating workforce to other areas (higher added value)	• Labor market changes	• Resource efficiency • Higher quality of work • Optimized human-machine interaction • Higher safety features • Employee involvement • Security of employment • Novel jobs
L – Law		• Legal requirements • Changed legislation (e.g. CE labeling) • Customer requirements	• Customer requirements • Customers' expectations	• Customer requirements • Customer needs	
	(Kiel et al., 2017)				
T – Technological	• Overall equipment effectiveness • Optimization of product and process quality • Higher productivity • Machine availability • Production process and output robustness • Lower scrap and failure rates • Self-optimization of machinery • Access to data and information • Flexible production • Tailoring the offer of products, services and hybrid solutions to customer needs – customization				
	(Müller et al., 2018)		(Stentoft et al., 2019)		
E – Environmental	• Reduction of environmental impact		• Efforts to save energy and improve sustainability		

Source: own work.

Table 2.
Barriers for Industry 4.0 implementation

Group	**Barriers from literature sources:**				
	(Müller et al., 2018)	**(Stentoft et al., 2019)**	**(Horváth, Szabó, 2019)**	**(Vuksanovic et al., 2020)**	**(Kiel et al., 2017)**
P – Political	• Existing business models endangered • High level of standardization • Too much Transparency • Loss of flexibility	• Lack of standards • Lack of understanding of strategies and the importance of I4.0 • Greater focus on operations at the expense of business development	• Standardization problems • Difficulty of coordination across organizational units • Lack of conscious planning: defining goals, steps and needed resources • Inadequate organizational structure and process organization • Contradictory interests in different organizational units	• Organizational challenges (planning system, protocols, coordination)	• Threatened future viability • Missing out on technological trends • Following wrong standards • Organizational transformation
E – Economical	• Loss of flexibility • High implementation costs • High effort, e.g. for standardization	• Too few financial resources	• Shortage of financial resources • Risk of fragility • Return and profitability • Shortcomings in tendering systems • Long evaluation period for tenders	• Financial issues	• Financial resources & profitability • High investments into technology development • Skilled workers and data security • Uncertain profitability

Cont. table 2.

S – Social	• Employee fear and concerns • Lack of expertise	• Too few human resources • Lack of qualified workforce • Lack of knowledge about I4.0 • Needs for continued education of employees • Lack of employee readiness • Lack of understanding the interaction between technology and human	• Human resources • Working conditions • Lack of planning skills and activities performance • Organizational resistance • Lack of appropriate competences and skilled workforce • Longer learning time (training of staff) • Lack of a leader with appropriate skills, competencies, and experience • Resistance by employees and middle management • Lack of willingness to cooperate (at the supply chain level) • Lack of proper, common thinking	• Managers' and employees' competences • Resistance	• Qualification of employees for process planning and coordination responsibilities • Needs of adequate training and development approaches • Long-term employee loyalty against the background of skilled worker shortage
T – Technological		• Lack of data protection (cybersecurity)	• Concerns about cybersecurity and data ownership issues • Technological integration • Lack of a unified communication protocol • Lack of back-end systems for integration • Lack of standards incl. technology and processes • Unsafe data storage systems • The need for large amounts of storage capacity		• Regionally limited bandwidth and Internet transfer speed
	(Kiel et al., 2017)				
L – Law	• Legal regulations of data ownership • Legal regulations of security aspects • Understanding of specific customer requirements				

Source: own work.

In the next step, all items were grouped by theme and area of interest. The final list of drivers and barriers is presented in Table 3. The political factors include internal and external considerations, government policy, but also internal company policy, including the organization's strategy. The economic factors are financial issues, efficiency, effectiveness, productivity, costs, profits, savings, etc. The social factors are related to work conditions and human resources while technological ones are broad technical requirements, constraints, and guidelines. The environmental factors are connected with improving sustainability and reducing the environmental impact. The legal factors concern customer requirements, law, and regulations.

Table 3.
Drivers and barriers for Industry 4.0 implementation

Group	Drivers	Barriers
P – Political	• New business models • Business model innovation • Opportunity for business model innovation • New product offerings • Innovative offerings • Increased innovation capacity • Increased competitiveness • Tracking market trends • Expansion and protection of market shares • Market competition • Competitiveness • Increased competitiveness • Increasing pressure from competitors • Implementation of Industry 4.0 by competitors • Improved time-to-market • Cost reduction • A deliberate strategy for Industry 4.0 • Demand for greater control (from top management) • Continuous monitoring of company performance • Initiation of work in cooperation with public advisory systems	• Existing business models endangered • High level of standardization • Lack of standards • Standardization problems • Following wrong standards • Lack of understanding of strategies and the importance of I4.0 • Lack of conscious planning: defining goals, steps, and needed resources • Inadequate organizational structure and process organization • Contradictory interests in different organizational units • Difficulty of coordination across organizational units • Organizational challenges (planning system, protocols, coordination) • Greater focus on operations at the expense of business development • Missing out on technological trends • Too much transparency • Threatened future viability
E – Economical	• Improving efficiency • Increasing productivity • Performance improvement • Load balancing • Shorter set-up • Shorter lead times • Faster machine speed • Reduction of non-value-adding activities and time • Increasing speed • Increasing flexibility • Facilitate faster and more flexible response to customer demands • Decrease of time-to-market • Growing sales volumes • Reducing the error rate • Ensuring reliable operation (e.g. less downtime) • Higher quality • Stock reduction • Costs reduction, e.g. human resources, inventory management, and operating costs • Finance • Performance factors	• High implementation costs • Too few financial resources • Lack of financial resources • High investments into technology development • High investments into skilled workers • High investments into data security • High effort, e.g. for standardization • Risk of fragility • Return and profitability • Loss of flexibility • Shortcomings in tendering systems • Long evaluation period for tenders

Cont. table 3.

S – Social	• Reduction of monotonous work • Age-appropriate workplaces • Novel jobs • Lack of qualified work force • Increasing labor shortages • Labor market changes • Security of employment • Reducing human work • Allocating workforce to other areas (higher added value) • Resource efficiency • Support for management activities • Higher quality of work • Optimized human-machine interaction • Higher safety features • Employee involvement	• Employee fear and concerns • Organizational resistance • Resistance by employees • Resistance by middle management • Lack of employee readiness • Lack of expertise • Lack of knowledge about I4.0 • Lack of qualified workforce • Needs for continued education of employees • Lack of appropriate competences and skilled workforce • Managers' competences • Employees' competences • Longer learning time (training of staff) • Needs of adequate training and development approaches • Qualification of employees for process planning and coordination responsibilities • Lack of planning skills and activities performance • Lack of a leader with appropriate skills, competencies and experience • Lack of proper, common thinking • Long-term employee loyalty against the background of skilled worker shortage • Too few human resources • Lack of understanding the interaction between technology and human • Working conditions • Lack of willingness to cooperate (at the supply chain level)
T – Technological	• Overall equipment effectiveness • Optimization of product and process quality • Higher productivity • Machine availability • Production process and output robustness • Lower scrap and failure rates • Self-optimization of machinery • Access to data and information • Flexible production • Tailoring the offer of products, services, and hybrid solutions to customer needs – customization	• Lack of data protection (cybersecurity) • Concerns about cybersecurity and data ownership issues • Unsafe data storage systems • Concerns about data ownership issues • Technological integration • Lack of a unified communication protocol • Lack of back-end systems for integration • Lack of standards incl. technology and processes • The need for large amounts of storage capacity • Regionally limited bandwidth and Internet transfer speed
E – Environ-mental	• Reduction of environmental impact • Efforts to save energy • Efforts to improve sustainability	
L – law	• Legal requirements • Changed legislation (e.g. CE labeling) • Customer requirements	• Legal regulations of data ownership • Legal regulations of security aspects

Source: own work.

3. Dimension of Industry 4.0 implementation and functional areas

The International Standard ISO 9001 issued in 2015 ("ISO 9001", 2015) defines the functional areas and describes the entire organization; from the establishment of the organization's structure, its processes, the required resources, through operational activities such as production, quality and logistics, to standardizing and managing changes. The map of the process and the interrelations between them help to define the functional areas: management processes (business management, quality management system, human resources management,

environmental management, occupational health and safety, etc.), core processes (sales, marketing, design, product development, engineering, production management, customer service, etc.), and supporting processes (maintenance, purchasing, quality control/assurance, finance and accounting). Table 4 shows the established list of functional areas for further research.

In order to verify the scope of Industry 4.0 dimensions another literature study was carried out, this time on the maturity models and the readiness to implement Industry 4.0 solutions (Amaral, Peças, 2021; Ariffin, Ahmad, 2021; Aziz et al., 2018; Baumgartner, Ebner, 2010; Caballero et al., 2008; Colli et al., 2019; Dobrowolska, Knop, 2020; Grabowska, 2021; Grufman, Lyons, 2020; Hamidi et al., 2018; Kryukov et al., 2022; Lucato et al., 2019; Mittal et al., 2018; Soomro et al., 2021; Sreedhanya, Balan, 2023; Stawiarska et al., 2021; Torres da Rocha et al., 2022; Yadav et al., 2020). The previous analysis and the results of the literature research, led to the development of a set of Industry 4.0 dimensions and, based on the area of interest, responsibility and competence, assigned to the functional areas of the organization. The final result of this analysis is presented in Table 4.

Table 4.
Functional areas and dimensions of Industry 4.0 implementation

#	Functional areas	Dimensions
1	Company management	Business
		Business based smart operations
		Business model
		Change management
		Competitiveness perspective
		Corporate strategy
		Critical areas of intervention
		Digital business model and customer access
		Enact & Envision
		Governance
		Legal considerations
		Management
		Management strategy & organization
		Organization and democratization
		Organizational alignment
		Organizational structure
		Strategic level
		Strategy
		Strategy & organization
		Structure
2	CSR/ESG/EHS	CSR activities
		Environment
		Health and safety
		Society
		Socio-environmental level
		Sustainable development
3	Finance management	Asset management
		Financial level
		Law and tax

Cont. table 4.

4	HR management	Collaboration
		Communication
		Company culture
		Competences
		Culture
		Employee relationships
		Employees
		Employer branding
		Flexible working models
		HR development strategy
		Human resources
		Knowledge management
		Leadership
		Learning competence
		Organization employees' digital culture
		People
		Professional competence
		Resources
5	IT management	Acceptance and application of new technology and media
		Agile IT structure
		Application management
		Cross-sectional technology criteria
		Data and analysis as a key capability
		Data driven services
		Data governance
		Database integration
		Degree of networking
		Digitizing horizontal and vertical integration of the value chain
		Factory of the Future
		Horizontal integration
		Information
		Information and communication
		Information systems
		Integration
		IT security
		Location of data use
		Security
		Smart Factory
		Technology
		Time horizon of data analytics
		Vertical & horizontal integration
		Vertical integration
		Virtual world
6	Logistic management	Distribution control
		Inter-firm cooperation
		Logistic management
		Supply chain
		Value chain
7	Maintenance management	Physical world
		Resources
		Tool identification
8	Product management	Design
		Digital product development
		Digitalization of product portfolio
		Innovation ecosystem
		Innovation perspective
		Offered product and services
		Product innovation management
		Production management
		Products and services
		Smart product
		Technology based smart products

Cont. table 4.

9	Production management	Determining the residual tool life
		Enable
		Functional
		Manufacturing and operations
		Operational & process level
		Operations
		Organization of production & logistics
		Process
		Process orientation
		Process transformation
		Smart operations
		Technical aspects (production)
		Technology management
10	Quality management	Complaint handling
		Customers
		Degree of standardization
		Quality management

Source: own work.

4. Levels of implementation

The levels of maturity or readiness for implementing Industry 4.0 are defined differently in the subject literature, although a 5-point Likert scale is most commonly used (Ariffin, Ahmad, 2021; Baumgartner, Ebner, 2010; Caballero et al., 2008; Colli et al., 2019; Grufman, Lyons, 2020; Kryukov et al., 2022; Mittal et al., 2018; Stawiarska et al., 2021). Authors define the levels and their scope in different ways. An example of these definitions is shown in Table 5. (Ariffin, Ahmad, 2021) defined Level 1 as an "Initial" which was explained as: "There is a presence of the process, but it is unexpected with a weak control and reactive"; Level 2 – "Managed" as: "There is a project specified process but in reactive form"; Level 3 – "Defined" means: "There is an organizational process in a proactive form"; Level 4 – "Quantitatively Managed" – "The process is wholly measured and controlled" and Level 5 – "Optimizing" where "The process always focuses on improvement". (Grufman and Lyons, 2020) proposed to add Level 0 as an "Outsider" which "indicates that a company either does not know of Industry 4.0, thinks it is irrelevant or has not taken any steps towards an implementation"; Level 1: "Beginner" – "Company involves some steps taken towards Industry 4.0, such as doing pilot studies and having some system compatibility for industry 4.0."; Level 2: "Intermediate" – "Companies have implemented industry 4.0 to some extent into their strategies, and some investments are being made"; Level 3: "Experienced" – "Is assigned to companies that have an Industry 4.0 strategy, makes investments in more than a few areas. Also, necessary IT security is implemented, cloud is used for future expansions"; Level 4: "Expert" – "Companies already using and monitoring Industry 4.0, make investments in almost all areas, supported by interdepartmental innovation, IT-systems support almost all production and collect vast amounts of data also used for optimization"; Level 5: "Top performer's" – "Companies that have already implemented their Industry 4.0 strategy and monitor

implementations of other projects in the company, which is supported by investments across the company. The innovation department is covering the entire company; IT systems are fully implemented along with autonomous processes, collecting vast amounts of relevant data. The infrastructure fulfills all needs for integration, across the company's system (…). The IT architecture is flexible, IT security is at a comprehensive level and the competencies in the company are all expertise they need". Kryukov et al. (2022) proposed to focus on digitization and provide the following definition: Level 1: "Initial – Infrastructure, systems and services do not allow to get business effects from process automation"; Level 2: "Performed – Infrastructure consolidated, basic automation systems implemented, processes formalized"; Level 3: "Managed – The infrastructure meets the needs of enterprise management, a corporate management system is implemented, processes are managed and controlled"; Level 4: "Predictable – A single corporate information space has been created, systems and services automatically generate reports and forecasts in real time, the state of processes is predictable"; and final Level 5: "Optimizing – Infrastructure, systems and services adapt to the needs of the enterprise, process management is digitized".

Table 5.
Level of maturity/readiness for Industry 4.0

Source	**Level of maturity/readiness**					
	0	**1**	**2**	**3**	**4**	**5**
(Caballero et al., 2008)		Initial	Defined	Integrated	Quantitatively managed	Optimizing
(Baumgartner, Ebner, 2010)		Beginning	Elementary	Satisfying – acc. to requirement	Exceeds requirements	Outstanding/ sophisticated
(Mittal et al., 2018)	Incomplete	Performed	Managed	Established	Predictable	Optimizing
(Colli et al., 2019)		None	Basic	Aware	Autonomous	Integrate
(Grufman, Lyons, 2020)	Outsider	Beginner	Intermediate	Experienced	Expert	Top performer
(Ariffin, Ahmad, 2021)		Initial	Managed	Defined	Quantitatively managed	Optimizing
(Stawiarska et al., 2021)		Digitalization initiation	Basic digitalization	Departmental digitalization	Interdepartmental digitalization	Full digitalization – Top level of I4.0
(Kryukov et al., 2022)		Initial	Performed	Managed	Predictable	Optimizing

Source: own work.

For further research also 5-point Likert scale will be used. The definition proposed by (Stawiarska et al., 2021) has been adapted as: Level 1 – Non or initiation, Level 2 – Basic implementations, Level 3 – Departmental implementations/reactive approach, Level 4 – Interdepartmental implementations / proactive approach, Level 5 – Full implementation/system approach.

5. Research tool – GRID model

The planned research of drivers and barriers in Industry 4.0 solutions implementation is to be performed in SME from automotive sector in Poland. Manufacturing companies especially in automotive area have to be competitive and flexible because of fast development and multiple requirements and regulations. Small and medium-sized enterprises in this sector often have difficulties with finance, time, pressure, staff competence. This industry needs new technological solutions. The planned study aims to verify the factors that make SMEs in this sector decide to implement technology 4.0 and to check the barriers that hinder the introduction of projects in this area. Systematizing the strength of the interactions on the various dimensions of implementing Industry 4.0 in each functional area is intended to identify aspects on which the organization should focus first.

The survey questionnaire has two parts: metric and main questionnaire. The main questionnaire contains three groups. The first group of questions relates to the actual technologies of Industry 4.0 and the technologies that are for future implementation. The second group of questions concerns the driving forces and barriers, broken down into political, economic, social, environmental, technological, and legal factors. The last part of the questionnaire is a matrix with levels of progress in implementing Industry 4.0 in a specific functional area and for a specific dimension of the implementation of new technological solution. Limitations of developed research questionnaire is the subjectivity of choice of the functional areas and the number of dimensions of the implementation. Pilot studies will bring additional value with the guidelines and possible corrections and improvements.

The authors plan to visualize all the results from the planned study based on the designed model: GRID – Goal, Resources, Indicators, Dimensions. Every project, and especially Industry 4.0 projects, should have specific goals. A company that decides to implement new elements must plan its activities accordingly in order to define the end state. The goals in the GRID model represent the target level of progress: level 1 to 5. New technological developments are specific for each of functional areas: logistic, quality, production, maintenance, etc. and should be appropriately selected. Thus, D in GRID model represents the dimension that this particular tool will address and what needs it will cover. Adequate Resources are needed to achieve the target state: staff with specific knowledge and experience, provision of financial resources, timetable, etc. Indicators should serve as metrics to verify each phase of the project, as well as to ultimately verify the effectiveness and efficiency of the measures put in place.

GRID can be a useful tool, as it allows visualization of the target state for each implementation dimension, as well as showing the current state. It can also be used as a tool to plan and monitor the implementation of technology solutions. In this case, the organization would need to define a target for the implementation of a specific technology, e.g. automation

of production processes, increased productivity, etc. Another topic to plan and track would be to clearly define the functional areas and their dimensions. It is also important to plan resources accordingly, such as finances, team, infrastructure, etc. Summary and conclusion

The development of the research tool presented in this thesis is mainly based on literature research on topics related to the implementation of Industry 4.0 in small and medium-sized enterprises and models of organizational readiness and maturity. The analyzed literature provided the desired background data in terms of theoretical foundations. Described research tool will be used in planned research covering small and medium-sized production organizations operating in the automotive sector in Poland. Specifically, these companies are mainly suppliers of materials and components. They are all affected by the numerous requirements of the industry, needs of flexibility and competitiveness. Industry 4.0 may be the answer to increasing their efficiency and effectiveness. The proposed research tool will allow obtaining information on the specific driving forces – the reasons why these enterprises decide to implement Industry 4.0 solutions and those elements that significantly hinder these implementations. The results of the final study will rank the identified barriers and factors driving the implementation of Industry 4.0 in terms of the strength of interaction on various dimensions of the implementation of Industry 4. Visualization of the analysis results in individual functional areas using the proposed GRID model will illustrate the current state of the organization and the target state which, in turn, will give measurable utilitarian benefits. This tool can also be used for self-assessment of the organization at the time of making decisions related to the implementation. The limitation of this tool is the number and selected functional areas as well as selected dimensions. It is necessary to carry out a pilot study on the basis of which guidelines for its possible correction and improvement will be developed.

References

1. Amaral, A., Peças, P. (2021). A Framework for Assessing Manufacturing SMEs Industry 4.0 Maturity. *Applied Sciences, Multidisciplinary Digital Publishing Institute, Vol. 11, No. 13,* p. 6127, doi: 10.3390/app11136127.
2. Ariffin, K.A.Z., Ahmad, F.H. (2021). Indicators for maturity and readiness for digital forensic investigation in era of industrial revolution 4.0. *Computers & Security, Vol. 105*, p. 102237, doi: 10.1016/j.cose.2021.102237.
3. Aziz, N.F.A., Suhaimi, A.N.M., Wozzari, N.A., Fadzil, S.Y.M. (2018). Just In Mobile Augmented Reality Technology (JIMART) Application. In: A.M. Lokman, T. Yamanaka, P. Lévy, K. Chen, S. Koyama (Eds.), *Proceedings of the 7th International Conference on Kansei Engineering and Emotion Research, Vol. 739*, pp. 54-63, doi: 10.1007/978-981-10-8612-0_7.

4. Bajic, B., Rikalovic, A., Suzic, N., Piuri, V. (2021). Industry 4.0 Implementation Challenges and Opportunities: A Managerial Perspective. *IEEE Systems Journal, Vol. 15, No. 1*, pp. 546-559, doi: 10.1109/JSYST.2020.3023041.
5. Baumgartner, R.J., Ebner, D. (2010). Corporate sustainability strategies: sustainability profiles and maturity levels. *Sustainable Development, Vol. 18, No. 2*, pp. 76-89, doi: 10.1002/sd.447.
6. Caballero, I., Caro, A., Calero, C., Piattini, M. (2008). IQM3: Information Quality Management Maturity Model. *Journal of Universal Computer Science, Vol. 14, No. 22*, pp. 3658-3685.
7. Colli, M., Berger, U., Bockholt, M., Madsen, O., Møller, C., Wæhrens, B.V. (2019). A maturity assessment approach for conceiving context-specific roadmaps in the Industry 4.0 era. *Annual Reviews in Control, Vol. 48*, pp. 165-177, doi: 10.1016/j.arcontrol. 2019.06.001.
8. Dobrowolska, M., Knop, L. (2020). Fit to Work in the Business Models of the Industry 4.0 Age. *Sustainability, Vol. 12, No. 12*, p. 4854, doi: 10.3390/su12124854.
9. Grabowska, S. (2021). *Model Biznesu 4.0. Architektura, Tworzenie Wartości, Ocena Konkurencyjności i Efektywności*. Toruń: TNOiK.
10. Grufman, N., Lyons, S. (2020). *Exploring Industry 4.0. A Readiness Assessment for SMEs*. Stockholm: Stockholm University, doi: 10.13140/RG.2.2.12170.08647.
11. Hamidi, S.R., Aziz, A.A., Shuhidan, S.M., Aziz, A.A., Mokhsin, M. (2018). SMEs Maturity Model Assessment of IR4.0 Digital Transformation. In: A.M. Lokman, T. Yamanaka, P. Lévy, K. Chen, S. Koyama, (Eds.), *Proceedings of the 7th International Conference on Kansei Engineering and Emotion Research*, pp. 721-732, doi: 10.1007/978-981-10-8612-0_75.
12. Hilkenmeier, F., Fechtelpeter, C., Decius, J. (2021). How to foster innovation in SMEs: evidence of the effectiveness of a project-based technology transfer approach. *Journal of Technology Transfer*, doi: 10.1007/s10961-021-09913-x.
13. Horvat, D., Stahlecker, T., Zenker, A., Lerch, C., Mladineo, M. (2018). A conceptual approach to analysing manufacturing companies' profiles concerning Industry 4.0 in emerging economies. *Procedia Manufacturing, Vol. 17*, pp. 419-426, doi: 10.1016/j.promfg.2018.10.065.
14. Horváth, D., Szabó, R.Zs. (2019). Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? *Technological Forecasting and Social Change, Vol. 146*, pp. 119-132, doi: 10.1016/j. techfore.2019.05.021.
15. Karamitsos, I., Apostolopoulos, C., Bugami, M.A. (2010). Benefits Management Process Complements Other Project Management Methodologies. *Journal of Software Engineering and Applications, Vol. 3, No. 9*, pp. 839-844, doi: 10.4236/jsea.2010.39097.

16. Kiel, D., Müller, J., Arnold, C., Voigt, K.-I. (2017). Sustainable Industrial Value Creation: Benefits and Challenges of Industry 4.0. *XXVIII ISPIM Innovation Conference – Composing the Innovation Symphony.* Austria, Vienna, pp. 1-21.
17. Kryukov, V., Shakhgeldyan, K., Kiykova, E., Kiykova, D., Saychuk, D. (2022). Assessment of transport enterprise readiness for digital transformation. *Transportation Research Procedia, Vol. 63*, pp. 2710-2718, doi: 10.1016/j.trpro.2022.06.313.
18. Lucato, W.C., Pacchini, A.P.T., Facchini, F., Mummolo, G. (2019). Model to evaluate the Industry 4.0 readiness degree in Industrial Companies. *IFAC-PapersOnLine, Vol. 52, No. 13*, pp. 1808-1813, doi: 10.1016/j.ifacol.2019.11.464.
19. Michna, A., Kmieciak, R. (2020). Open-Mindedness Culture, Knowledge-Sharing, Financial Performance, and Industry 4.0 in SMEs. *Sustainability, Vol. 12, No. 9041*, pp. 1-17, doi: 10.3390/su12219041.
20. Michna, A., Kmieciak, R., Kruszewska, J. (2021). Industry 4.0 Implementation in automotive sector: driving forces, barriers and competencies. Pilot empirical study. *Proceedings of the 38th International Business Information Management Association (IBMIA).* Seville, Spain, pp. 9444-9450.
21. Michna, A., Kruszewska, J. (2020). Industry 4.0 solution implementation factors: driving forces, barriers and chances. Planned research of SME. *Proceedings of the 36th International Business Information Management Association (IBMIA).* Granada, Spain, pp. 13924-13927.
22. Michna, A., Kruszewska, J. (2021). Driving Forces, Barriers and Competencies in Industry 4.0 Implementation. *Proceedings of the 37th International Business Information Management Association (IBMIA).* Cordoba, Spain, pp. 11112-11117.
23. Michna, A., Kruszewska, J. (2022). Determining the Level of Use of the Industry 4.0 Solutions in the COVID-19 Pandemic Era: Results of Empirical Research. *Sustainability, Vol. 14, No. 14,* p. 8844, doi: 10.3390/su14148844.
24. Mittal, S., Khan, M.A., Romero, D., Wuest, T. (2018). A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs). *Journal of Manufacturing Systems, Vol. 49*, pp. 194-214, doi: 10.1016/j.jmsy.2018.10.005.
25. Müller, J.M. (2019). Assessing the barriers to Industry 4.0 implementation from a workers' perspective. *IFAC-PapersOnLine, Vol. 52, No. 13*, pp. 2189-2194, doi: 10.1016/j. ifacol.2019.11.530.
26. Müller, J.M., Kiel, D., Voigt, K.-I. (2018). What Drives the Implementation of Industry 4.0? The Role of Opportunities and Challenges in the Context of Sustainability. *Sustainability, Vol. 10, No. 1*, pp. 1-24, doi: 10.3390/su10010247.
27. PN-EN ISO 9001:2015 (2015). Retrieved from: https://www.iso.org/standard/62085.html, 4.01.2023.

28. Soomro, M.A., Hizam-Hanafiah, M., Abdullah, N.L., Jusoh, M.S. (2021). Change readiness as a proposed dimension for Industry 4.0 readiness models. *LogForum, Vol. 17, No. 1*, pp. 83-96.
29. Sreedhanya, L.R., Balan, S. (2023). Industry 4.0 Framework Using 7-layer Architecture for Smart Factory Application. *Lecture Notes in Networks and Systems, Vol. 401*, pp. 323-332, doi: 10.1007/978-981-19-0098-3_32.
30. Stawiarska, E., Szwajca, D., Matusek, M., Wolniak, R. (2021). Diagnosis of the Maturity Level of Implementing Industry 4.0 Solutions in Selected Functional Areas of Management of Automotive Companies in Poland. *Sustainability, Vol. 13, No. 9*, p. 4867, doi: 10.3390/su13094867.
31. Stentoft, J., Jensen, K.W., Philipsen, K., Haug, A. (2019). Drivers and Barriers for Industry 4.0 Readiness and Practice: A SME Perspective with Empirical Evidence. *Proceedings of the 52nd Hawaii International Conference on System Sciences*, pp. 5155-5164.
32. Torres da Rocha, A.B., Borges de Oliveira, K., Espuny, M., Salvador da Motta Reis, J., Oliveira, O.J. (2022). Business transformation through sustainability based on Industry 4.0. *Heliyon, Vol. 8, No. 8*, doi: 10.1016/j.heliyon.2022.e10015.
33. Türkeș, M., Oncioiu, I., Aslam, H., Marin-Pantelescu, A., Topor, D., Căpușneanu, S. (2019). Drivers and Barriers in Using Industry 4.0: A Perspective of SMEs in Romania. *Processes, Vol. 7, No. 3*, p. 153, doi: 10.3390/pr7030153.
34. Veile, J.W., Kiel, D., Müller, J.M., Voigt, K.I. (2019). Lessons learned from Industry 4.0 implementation in the German manufacturing industry. *Journal of Manufacturing Technology Management, Vol. 31, No. 5*, pp. 977-997, doi: 10.1108/JMTM-08-2018-0270.
35. Veile, J.W., Schmidt, M.C., Müller, J.M., Voigt, K.I. (2020). Relationship follows technology! How Industry 4.0 reshapes future buyer-supplier relationships. *Journal of Manufacturing Technology Management, Emerald Publishing Limited, Vol. 32, No. 6*, pp. 1245-1266, doi: 10.1108/JMTM-09-2019-0318.
36. Vuksanović Herceg, I., Kuč, V., Mijušković, V.M., Herceg, T. (2020). Challenges and Driving Forces for Industry 4.0 Implementation. *Sustainability, Vol. 12, No. 4208*, pp. 1-22, doi: 10.3390/su12104208.
37. Yadav, G., Kumar, A., Luthra, S., Garza-Reyes, J.A., Kumar, V., Batista, L. (2020). A framework to achieve sustainability in manufacturing organisations of developing economies using industry 4.0 technologies' enablers. *Computers in Industry, Vol. 122*, p. 103280, doi: 10.1016/j.compind.2020.103280.

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EFFICIENCY OF INVESTMENT PORTFOLIOS DURING THE COVID-19 PANDEMIC AND THE WAR IN UKRAINE

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Purpose: The aim of the conducted research is to examine the efficiency of portfolios composed of companies listed on the Warsaw Stock Exchange in the subsequent quarters of 2018-2023.
Design/methodology/approach: The classical Markovitz approach and the TMAI measure, beta coefficient and Sharpe ratio were used to determine the shares of optimal portfolios. The expected rate of return, realized rate of return, portfolio risk and Sharpe ratio will be used to assess the efficiency of companies.
Findings: The analysis conducted allowed to build investment portfolios, assess their efficiency and indicate a portfolio that systematically gives a better result than the portfolio containing all the analyzed companies. The obtained results allowed us to state that in the analyzed period, the "best" portfolio is the portfolio based on the problem of maximizing the linear combination of Sharpe ratios. The outbreak of the Covid-19 pandemic and the war in Ukraine significantly affected the rates of return of investment portfolios. In the case of the strongest restrictions related to the pandemic, positive rates of return were brought by the portfolio that is a solution to the problem of minimizing the linear combination of beta coefficients.
Research limitations/implications: The financial condition of a company, estimated using the TMAI measure, is a variable that is not directly measurable. Its value is generated by observations of diagnostic variables, which are a subjective choice of the researcher. This choice should be made in a reliable manner, preceded by studies of the appropriate literature. The Sharpe ratio requires the assumption of the normality of the distribution of return rates, but in practice this assumption is rarely met. When determining the beta coefficient, the length of the period that should be used to estimate the Sharpe model equation should be determined, because as the number of observations increases, the assumption of linear dependence is not met.
Practical implications: The presented methods of determining company shares allow to indicate a portfolio that systematically gives a better result than the reference portfolio containing all analyzed companies. The existence of such a portfolio allows to use such measures as TMAI, beta or Sharpe to estimate optimal portfolios.
Social implications: What will be the impact on society of this research? How will it influence public attitudes? How will it influence (corporate) social responsibility or environmental issues? How could it inform public or industry policy? How might it affect quality of life? Not all papers will have social implications.

Originality/value: Showing that using the TMAI measure, beta coefficient and Sharpe ratio to build an investment portfolio even in "difficult" times, such as the COVID-19 pandemic or the outbreak of war in Ukraine, allows you to create a portfolio that gives better results than the reference portfolio. The methods used are useful for entrepreneurs and investors.
Keywords: investment portfolio, TMAI measure, Sharpe ratio, beta coefficient.
Category of the paper: research paper.

1. Introduction

The company's environment (both internal and external) is one of the main determinants of its functioning and development. The environment includes not only other entities related to the functioning of the company, but also phenomena and processes that are outside the company and over which the company has no influence. One of such unpredictable phenomena referred to as a "black swan" (Szczepański, 2020) was the outbreak of the Covid-19 pandemic. The pandemic has left a significant mark on the global economy. Its consequences in the form of restrictions, restrictions and sanitary regimes, as well as their subsequent loosening or lifting, have been and continue to be felt in various sectors of the economy. Already in 2020, many works appeared on the impact of the outbreak of the Covid-19 pandemic on socio-economic phenomena, i.e.: asset price and aggregate demand spirals and the supply shock associated with the Covid-19 virus (Caballero, Simsek, 2020), household consumption (Baker et al., 2020), real-time economic activity indicator in the United States (Lewis et al., 2020), changes in country credit ratings (Chodnicka-Jaworska, 2020).

Emotional factors accompanying the pandemic also had a significant impact on the decisions made by investors on financial markets. People's psychological conditions and the moods prevailing on the stock market play an important role in the decision-making process. Irrational investor behavior, especially herd effects, was particularly visible during the pandemic. In her research, Wiśniewska (2022) showed that the outbreak of the coronavirus pandemic did not reduce the activity of Polish investors, and caused a significant increase in interest in shares of companies listed on the Warsaw Stock Exchange. In the face of the developing pandemic, investor behavior and their attitude to risk changed, through the rapid purchase of discounted securities or rapid asset sales (Wiśniewska, 2022).

Studies conducted on the SARS epidemic have shown that this epidemic led to a financial crisis in Asia, as a result of which investors suffered losses on the stock market estimated at USD 2 trillion (DeLisle, 2003). Other studies have shown that during various epidemics, investors were most often pessimistic about investment prospects, which could result in selling securities out of fear of more severe consequences of the epidemic (Bai, 2014; Baker, Wurgler, Yuan, 2012).

Haiyue Liu et al. (2020) found that the outbreak of the Covid-19 pandemic had a significant negative impact on the returns of stock indices in all the countries selected for the study. Asian markets responded faster to the outbreak of the epidemic, and some of them saw an improvement in the later stage of the pandemic. The authors showed that confirmed cases of the disease had a significant negative impact on the performance of the main stock indices. (Haiyue Liu et al., 2020)

However, the Jaworski study (2021) showed a statistically significant impact of the announcement of a national quarantine or its relaxation or lifting on global stock market indices, with a stronger reaction recorded in the case of the announcement of a quarantine than in the case of its relaxation.

The aim of the study was to assess the effectiveness of investment portfolios created from shares of companies included in the WIG30 and mWIG40 indices listed on the Warsaw Stock Exchange during the Covid-19 pandemic and the outbreak of war in Ukraine. In this way, an attempt will be made to answer the question of whether it is possible to build an optimal portfolio that gives better results than the reference portfolio built from all analyzed companies. In order to assess the effectiveness of the portfolios, the expected rate of return, the realized rate of return, portfolio risk and the Sharpe ratio will be used.

2. TMAI measure, Sharpe ratio, beta coefficient

The taxonomic measure of investment attractiveness TMAI proposed by W. Tarczyński (1994) is a linear ordering method based on a synthetic variable. Its values are estimated based on financial indicators describing companies. The estimated values of the synthetic variable allow for the arrangement of companies in terms of their financial condition. The following stages can be distinguished in the linear arrangement procedure: determining the nature of variables, determining the weights of variables, normalizing variables, determining the coordinates of the pattern in the case of pattern aggregation, pattern less or pattern aggregation, classification of ranked objects and recognition of development types (Bąk, 2016).

The construction of TMAI is based on estimating the distance of each object from the reference object using the formula (Tarczyński, 2002):

$$d_i = \left[\frac{\sum_{j=1}^{m} \left(y_{ij} - y_{0j} \right)^2}{m} \right]^{1/2}, \quad i = 1, ..., n; \tag{1}$$

where:

d_i – distance of the i-th object from the pattern object,

y_{0j} – pattern object, established on the basis of a formula.

$$y_{0j} = \max_i \{y_{ij}\}, \tag{2}$$

y_{ij}, m – as above.

The final step is TMAI normalization:

$$TMAI_i = 1 - \frac{d_i}{d_0}, \quad i = 1, \ldots, n; \tag{3}$$

where:

$TMAI_i$ – taxonomic measure of the attractiveness of the i-th object,

d_0 – norm that ensures that $TMAI_i$ take values from the interval $[0,1]$,

$$d_0 = \bar{d} + 2S_d, \tag{4}$$

$\bar{d}, S_d$ – arithmetic mean and standard deviation d_i.

One of the first measures of investment efficiency, proposed in 1966, is the Sharpe ratio, which is estimated as the ratio of the excess of the average rate of return over the risk-free rate to the standard deviation:

$$S = \frac{\bar{R} - R_f}{\sigma} \tag{5}$$

where:

$\bar{R}$ - average rate of return,

R_f - average risk-free rate,

σ - risk measured by standard deviation.

The Sharpe ratio requires the assumption of normality of the distribution of return rates, but in practice this assumption is rarely met (Bernardo, Ledoit, 2000). For this reason, many measures have been created that are modifications of the Sharpe ratio, based on a different construction or other assumptions regarding the risk measure (Pezier, White, 2006; Modigliani, Modigliani, 1997; Konno, Yamazaki, 1991; Watanabe, 2007; Le Sourd, 2007). However, research shows that many of these measures are correlated (Wiesinger, 2010; Żebrowska-Suchodolska,

The Sharpe model is one of the most popular models for capital market analysis, mainly due to the possibility of using the β coefficient as a measure of risk. The classic Sharpe model is of the form (Tarczyński, 1997):

$$R_{it} = \alpha + \beta \cdot R_{mt} + U_t \tag{6}$$

where:

R_{it} – share rate of return for the i-th company,

α, β – structural parameters of the model,

R_{mt} – market rate of return,

U_t – random component.

The parameters α, β are estimated using the least squares method. When using the above model, the length of the period that should be used to estimate the equation should be determined, because as the number of observations increases, the key assumption of linear dependence in the Sharpe model is not met. Tarczyński (2009) proposes a period of 10 last quotations using a confirmatory procedure based on the analysis of the R^2 coefficient, the R^2 increment and the Student's t-test.

3. Optimal investment portfolios

The basic characteristics describing stock portfolios are the expected portfolio rate of return and portfolio risk, calculated using the formulas:

$$R_p = \sum_{i=1}^{m} x_i R_i \,, \tag{7}$$

$$S_p^2 = \sum_{i=1}^{m} x_i^2 S_i^2 + 2\sum_{i=1}^{m-1} \sum_{j=i+1}^{m} x_i x_j S_i S_j \rho_{ij} \,, \tag{8}$$

where:

R_p – expected rate of return of the portfolio of m shares,

S_p – risk of the portfolio of ma shares,

R_i – expected rate of return of the i-th share,

S_i – standard deviation of the i-th share,

ρ_{ij} – correlation coefficient of i-th stock with j-th stock,

x_i - share of i-th share in the portfolio,

$$\sum_{i=1}^{m} x_i = 1, \quad x_i \geq 0, \quad i = 1, ..., m, \tag{9}$$

m – number of shares in the portfolio.

The shares of stocks in the portfolio are usually determined based on the H. Markowitz model (Markowitz, 1952), so as to minimize the risk of this portfolio (Problem 1). Another frequently used approach is the task of maximizing the expected rate of return (Problem 2).

Problem 1

$$minS_p^2$$

subject to:

$$R_p \geq R_0$$

$$\sum_{i=1}^{n} x_i = 1$$

$$x_i \geq 0, i = 1, 2, \ldots, n$$

Problem 2

$$maxR_p$$

subject to:

$$\sum_{i=1}^{n} S_i x_i \leq S_0$$

$$\sum_{i=1}^{n} x_i = 1$$

$$x_i \geq 0, i = 1, 2, \ldots, n$$

where: R_0– expected rate of return, other symbols as above.

To determine the shares of financial instruments in the optimal portfolio, linear ordering methods can be used, i.e. the relative development level index (RDI), the generalized distance measure (GDM) and the synthetic development measure (TMAI).

Problem 3

$$max \sum_{i=1}^{n} TMAI_i x_i$$

subject to:

$$R_p \geq R_0$$

$$\sum_{i=1}^{n} S_i x_i \leq S_0$$

$$\sum_{i=1}^{n} x_i = 1$$

$$x_i \geq 0, i = 1, 2, \ldots, n$$

where: symbols as above.

The following optimization problems based on the beta coefficient (Problem 4) and the Sharpe ratio (Problem 5) were also used in the study:

Problem 4

$$min \sum_{i=1}^{n} \beta_i x_i$$

subject to:

$$R_p \geq R_0$$

$$\sum_{i=1}^{n} S_i x_i \leq S_0$$

$$\sum_{i=1}^{n} x_i = 1$$

$$x_i \geq 0, i = 1, 2, \ldots, n$$

where: symbols as above.

Problem 5

$$max \sum_{i=1}^{n} S_i x_i$$

subject to:

$$R_p \geq R_0$$

$$\sum_{i=1}^{n} x_i = 1$$

$$x_i \geq 0, i = 1, 2, \ldots, n$$

4. Empirical study

The study covered 51 companies listed on the Warsaw Stock Exchange, included in the WIG30 and mWIG40 indices in the period from 1 October 2018 to 31 March 2023. The study excluded companies from the financial sector and companies that were not listed throughout the period under consideration or had missing data. The following companies were taken into account: Amica, Amrest, Asbis, Assecopol, Azoty, Benefit, Bogdanka, Boryszew, Budimex, Bumech, CDProjekt, Ciech, CIGames, Comarc, Cormav, CyfPolsat, Datawalk, Develia, DinoPL, Domdevel, Echo, Enea, Energa, EuroCash, Forte, GPW, Grenevia, GTC, Intercars, JSW, Kernel, Kety, KGHM, KrukSA, LiveChat, Mercator, Mobruk, Neuca, OrangePL, Pak, Pep, PGE, PKNOrlen, PKPCargo, Playway, Polimex, Stalprod, Tauron, Trakcja, TSGames, VRG.

In order to determine the TMAI measure for each company, financial indicators were taken into account for each quarter in the period from 1.10.2018 to 1.4.2023 (18 quarters). The study used the following indicators from the Notoria database: operating profit margin, gross profit margin, net profit margin, return on equity (ROE), return on assets (ROA), current liquidity ratio, quick liquidity ratio, increased liquidity ratio, receivables turnover, inventory turnover, operating cycle, liabilities turnover, cash conversion cycle, current assets turnover, asset turnover, asset coverage ratio, debt ratio.

In each quarter in the period from 1.10.2018 - 31.03.2023 5 optimal portfolios were constructed, which were solutions to the optimization problems 1-5 (90 portfolios) and one reference portfolio containing shares of all companies covered by the study in a given quarter (18 portfolios). Each portfolio was purchased on the 1st day of the quarter and sold on the 1st day of the following quarter at closing prices. The following were used to assess the portfolios: expected rate of return, portfolio risk, realized rate of return, Sharpe ratio. Since estimating the Sharpe ratio requires knowledge of the risk-free interest rate for each period, its value was assumed at the level of the 3M WIBOR rate on the day of construction of subsequent portfolios.

Table 1 presents the expected rates of return for portfolios constructed in subsequent quarters of the years 2018-2023. Expected rates of return that were higher than the expected rate of return of the reference portfolio in a given quarter are marked in bold.

Table 1.
Expected rates ofreturn of the constructed portfolios

	01.01.2019	**01.04.2019**	**01.07.2019**	**01.10.2019**	**01.01.2020**	**01.04.2020**	**01.07.2020**	**01.10.2020**	**01.01.2021**
max Sharpe	-0,09%	**0,38%**	**0,44%**	**0,31%**	**0,69%**	**0,50%**	**1,22%**	**0,58%**	**0,92%**
min Beta	-0,06%	**0,21%**	**0,00%**	**0,09%**	**0,17%**	**-0,14%**	**0,64%**	**0,16%**	**0,36%**
max TMAI	**-0,06%**	**0,30%**	**0,07%**	**0,13%**	**0,25%**	**-0,03%**	**0,64%**	**0,16%**	**0,33%**
max Rp	**0,32%**	**0,78%**	**0,49%**	**0,36%**	**0,71%**	**0,56%**	**1,24%**	**0,78%**	**0,92%**
min Sp	-0,06%	**0,18%**	**0,05%**	**0,03%**	**0,17%**	**-0,09%**	**0,64%**	**0,16%**	0,29%
reference portfolio	-0,06%	0,17%	-0,01%	-0,07%	0,15%	-0,35%	0,61%	0,15%	0,29%

	01.04.2021	**01.07.2021**	**01.10.2021**	**01.01.2022**	**01.04.2022**	**01.07.2022**	**01.10.2022**	**01.01.2023**	**01.04.2023**
max Sharpe	**0,73%**	**0,59%**	**0,46%**	**0,22%**	**0,07%**	**0,40%**	**0,10%**	**0,62%**	**0,47%**
min Beta	0,16%	0,13%	**0,15%**	**0,02%**	0,02%	**0,08%**	-0,10%	**0,23%**	0,06%
max TMAI	0,16%	0,13%	**0,15%**	**0,07%**	0,02%	**-0,09%**	-0,10%	**0,30%**	**0,40%**
max Rp	**0,74%**	**0,59%**	**0,67%**	**0,29%**	**0,65%**	**0,56%**	**0,43%**	**0,69%**	**0,53%**
min Sp	0,16%	0,13%	**0,15%**	**-0,03%**	0,02%	**-0,09%**	**-0,02%**	**0,23%**	0,06%
reference portfolio	0,16%	0,13%	0,14%	-0,06%	0,03%	-0,08%	-0,10%	0,22%	0,07%

Source: own elaboration.

A comparison of the expected rates of return obtained for the individual portfolios with the expected rate of return of the reference portfolio indicates that during the period under review, the max Sharpe (solution to problem 5) and max Rp (solution to problem 2) portfolios had a higher expected rate of return than the reference portfolio seventeen times. The max TMAI portfolio (solution to problem 3) had a higher expected rate of return than the reference portfolio 14 times, and the min Beta (solution to problem 4) and min Sp (solution to problem 1) portfolios 12 times.

Table 2 presents the risk of portfolios constructed in subsequent quarters of the years 2018-2023. The risk of portfolios that were lower than the risk of the reference portfolio in a given quarter is marked in bold.

Table 2.
Risk of the constructed portfolios

	01.01.2019	**01.04.2019**	**01.07.2019**	**01.10.2019**	**01.01.2020**	**01.04.2020**	**01.07.2020**	**01.10.2020**	**01.01.2021**
max Sharpe	16,23%	14,74%	15,64%	14,44%	14,38%	20,78%	18,87%	18,07%	17,93%
min Beta	17,52%	**13,77%**	**15,36%**	14,43%	14,91%	**14,59%**	**17,54%**	**15,61%**	19,44%
max TMAI	**15,82%**	**14,28%**	**14,41%**	**11,44%**	**10,78%**	**17,14%**	**18,03%**	**16,47%**	17,91%
max Rp	15,86%	21,69%	15,69%	14,44%	14,38%	20,76%	18,85%	18,06%	17,93%
min Sp	**11,81%**	**9,74%**	**8,52%**	**8,45%**	**7,63%**	**11,61%**	**14,41%**	**11,49%**	**11,53%**
reference portfolio	15,84%	14,59%	15,45%	14,28%	14,18%	20,54%	18,73%	17,98%	17,70%

	01.04.2021	**01.07.2021**	**01.10.2021**	**01.01.2022**	**01.04.2022**	**01.07.2022**	**01.10.2022**	**01.01.2023**	**01.04.2023**
max Sharpe	15,88%	15,02%	15,23%	16,07%	19,06%	17,11%	17,03%	16,14%	14,96%
min Beta	**13,16%**	16,79%	**13,47%**	18,94%	20,35%	**15,65%**	16,86%	**13,53%**	**12,67%**
max TMAI	**15,40%**	15,04%	15,16%	16,10%	19,09%	17,11%	17,02%	16,11%	**14,26%**
max Rp	15,88%	15,02%	15,23%	16,07%	19,00%	17,07%	17,02%	16,14%	14,94%
min Sp	**9,31%**	**8,45%**	**9,33%**	**7,50%**	**11,39%**	**9,82%**	**9,53%**	**10,67%**	**8,61%**
reference portfolio	15,72%	14,79%	15,14%	15,86%	18,85%	16,83%	16,82%	15,90%	14,71%

Source: own elaboration.

Based on the data presented in Table 2, it can be seen that the min Sp portfolio was characterized by a lower risk level than the reference portfolio 18 times, while the min Beta and max TMAI portfolios were characterized by a lower risk level than the reference portfolio 10 times. The max Rp portfolio had a higher risk level than the reference portfolio in each quarter.

Table 3 presents the realised rates of return for portfolios constructed in subsequent quarters of the years 2018-2023. The realised rates of return that were higher than the realised rate of return of the reference portfolio in a given quarter are marked in bold.

Table 3.
Realized rates of return of the constructed portfolios

	01.01.2019	**01.04.2019**	**01.07.2019**	**01.10.2019**	**01.01.2020**	**01.04.2020**	**01.07.2020**	**01.10.2020**	**01.01.2021**
max Sharpe	**11,69%**	**20,95%**	-3,29%	**34,67%**	**46,66%**	**73,26%**	**16,64%**	**25,27%**	**9,45%**
min Beta	**11,89%**	-19,06%	**14,94%**	8,12%	-14,79%	34,94%	**41,08%**	-4,80%	-5,00%
max TMAI	**30,54%**	**7,38%**	-2,54%	**34,96%**	**34,78%**	**68,82%**	**27,38%**	**9,28%**	-6,92%
max Rp	-13,23%	**30,98%**	**13,79%**	8,51%	**18,09%**	**64,31%**	**15,93%**	-5,52%	**9,45%**
min Sp	**23,95%**	**19,81%**	**3,26%**	**33,05%**	**23,80%**	**80,50%**	12,89%	0,10%	2,18%
reference portfolio	11,56%	-7,07%	2,28%	11,58%	-11,33%	39,41%	14,19%	8,54%	3,37%

	01.04.2021	**01.07.2021**	**01.10.2021**	**01.01.2022**	**01.04.2022**	**01.07.2022**	**01.10.2022**	**01.01.2023**	**01.04.2023**
max Sharpe	0,05%	**6,49%**	**-5,50%**	-29,91%	-14,33%	-14,48%	**18,73%**	-21,27%	**29,32%**
min Beta	2,79%	-5,80%	**-2,63%**	**6,26%**	**15,11%**	-23,08%	**39,05%**	11,87%	**31,71%**
max TMAI	-5,83%	-2,65%	**-4,03%**	-17,07%	-11,53%	**-0,97%**	**17,60%**	**26,40%**	-0,35%
max Rp	-8,18%	**6,49%**	-31,84%	-15,01%	-30,09%	**-7,40%**	**26,33%**	-15,08%	**29,53%**
min Sp	-5,74%	**8,98%**	-23,89%	-41,70%	-33,91%	-11,11%	**23,12%**	-17,57%	-2,64%
reference portfolio	6,33%	0,16%	-7,61%	-4,92%	-10,97%	-7,66%	13,49%	12,70%	12,69%

Source: own elaboration.

The analysis of realized rates of return showed that the max Sharpe portfolio achieved a higher rate of return than the reference portfolio 12 times, the max TMAI portfolio 11 times, and the max Rp portfolio 10 times. The remaining portfolios delivered a higher realized rate of return than the benchmark portfolio 10 times during the quarters under consideration.

Table 4 presents the cumulative rate of return, the geometric mean of realised rates of return and the average risk for portfolios constructed in subsequent quarters of the years 2018-2023. Values that were higher than the values obtained for the reference portfolio are marked in bold.

Table 4.
Cumulative rate of return, geometric mean rate of return and mean risk of the constructed portfolios

	cumulative rate of return	**geometric mean rate of return**	**mean risk**
max Sharpe	**346,97%**	**8,67%**	**16,53%**
min Beta	**200,10%**	**6,30%**	15,81%
max TMAI	**414,62%**	**9,53%**	15,64%
max Rp	66,32%	2,87%	**16,89%**
min Sp	39,27%	1,86%	9,99%
reference portfolio	107,70%	4,14%	16,33%

Source: own elaboration.

The analysis of cumulative rates of return (Table 4) showed that the max TMAI, max Sharpe and min Beta portfolios were characterized by a higher cumulative rate of return than the reference portfolio, in particular for the max TMAI portfolio this difference amounted to almost 307 percentage points. The max Rp and min Sp portfolios achieved the lowest cumulative rates of return, which were significantly lower than the cumulative rate of return for the reference portfolio. Based on the geometric average rates of return (Table 4), it can be seen that the max TMAI, max Sharpe and min Beta portfolios generated higher geometric average rates of return than the reference portfolio. The lowest geometric average was obtained for the min Sp portfolio, which was also characterized by the lowest average risk. However, it should be noted that the average risks obtained for the remaining portfolios are similar to each other and take values from the range (15.64%, 16.89%). The average level of risk was lower than the reference portfolio for the min Beta and max TMAI portfolios. The max TMAI portfolio, which had the highest cumulative realised rate of return and the highest geometric mean realised rate of return, had an average portfolio risk that was lower than the reference portfolio.

Table 5 presents the Sharpe ratios for the constructed portfolios. The Sharpe ratios that were higher than the Sharpe ratios of the reference portfolio in a given quarter are marked in bold.

Table 5.
Sharpe ratios of the constructed portfolios

	01.01.2019	**01.04.2019**	**01.07.2019**	**01.10.2019**	**01.01.2020**	**01.04.2020**	**01.07.2020**	**01.10.2020**	**01.01.2021**
max Sharpe	0,61	**1,30**	-0,32	**2,28**	**3,13**	**3,47**	**0,87**	**1,39**	**0,52**
min Beta	0,58	-1,51	**0,86**	0,44	-1,11	**2,31**	**2,33**	-0,32	-0,27
max TMAI	**1,82**	**0,40**	-0,30	**2,90**	**3,07**	**3,95**	**1,50**	**0,55**	-0,40
max Rp	-0,94	**1,35**	**0,77**	0,47	**1,14**	**3,04**	**0,83**	-0,32	**0,52**
min Sp	**1,88**	**1,86**	**0,18**	**3,71**	**2,90**	**6,83**	**0,88**	-0,01	0,17
reference portfolio	0,62	-0,60	0,04	0,69	-0,92	1,86	0,74	0,46	0,18

	01.04.2021	**01.07.2021**	**01.10.2021**	**01.01.2022**	**01.04.2022**	**01.07.2022**	**01.10.2022**	**01.01.2023**	**01.04.2023**
max Sharpe	-0,01	**0,42**	-0,38	-2,02	-1,00	-1,26	**0,68**	-1,75	**1,50**
min Beta	0,20	-0,36	-0,21	**0,20**	**0,51**	-1,93	**1,89**	**0,36**	**1,96**
max TMAI	-0,39	-0,19	-0,28	-1,22	-0,85	**-0,47**	**0,61**	**1,20**	-0,51
max Rp	-0,53	**0,42**	-2,11	-1,09	-1,83	**-0,85**	**1,12**	-1,37	**1,52**
min Sp	-0,64	**1,04**	-2,59	-5,90	-3,40	-1,85	**1,67**	-2,31	-1,11
reference portfolio	0,39	0,00	-0,52	-0,47	-0,84	-0,87	0,37	0,36	0,39

Source: own elaboration.

Based on the data presented in Table 5, it can be seen that the reference portfolio had a positive Sharpe ratio in 12 out of 18 analyzed quarters, which means that only in these years did it bring a rate of return higher than the risk-free rate. The constructed portfolios had a positive Sharpe ratio 9-12 times. The max Sharpe and max TMAI portfolios had a higher Sharpe ratio 11 times than the reference portfolio, of which 11 times this concerned positive values of the ratio for the max Sharpe portfolio and 9 times for the max TMAI portfolio. At the same time, the reference portfolio had a higher positive value of the ratio 4 times than the max Sharpe and max TMAI portfolio.

5. Summary

In The study assessed the efficiency of investment portfolios built from selected companies listed on the Warsaw Stock Exchange using 5 optimization tasks. Then, it was attempted to assess whether the selected optimization tasks allow for indicating a portfolio that systematically gives a better result than the reference portfolio containing all the analyzed companies. The conducted research allows for drawing the following conclusions:

- The obtained values of Sharpe ratios allow us to conclude that in the analyzed period the "best" portfolio is the max Sharpe portfolio, which is the solution to optimization problem 5.
- The analysis of geometric average rates of return of the constructed portfolios indicates that the max TMAI portfolio (solution to problem 3), maxSharpe (solution to problem 5), min Beta (solution to problem 4) portfolios brought higher geometric averages than the reference portfolio.
- Based on the conducted research, it can be seen that the outbreak of the Covid-19 pandemic and the war in Ukraine significantly affected the rates of return of investment portfolios. In the case of the strongest restrictions related to the pandemic, the Min beta portfolio, which is the solution to optimization problem 4, brought positive rates of return.

To sum up, it can be said that portfolios built on the basis of max Sharpe and max TMAI optimization problems allow for systematically achieving a higher rate of return than the reference portfolio.

References

1. Bąk, A. (2016). Porządkowanie liniowe obiektów metodą Hellwiga i TOPSIS – analiza porównawcza. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu, Taksonomia, 26, Klasyfikacja i analiza danych – teoria i zastosowania*, pp. 22-31.
2. Bernardo, A.E., Ledoit, O. (2000). Gain, Loss and Asset Pricing. *Journal of Political Economy, Vol. 108(1)*, pp. 144-172.
3. Jaworski, P. (2021). Wpływ pandemii Covid-19 na główne indeksy giełdowe na świecie. *Zarządzanie mediami, t. 9(1)*, pp. 157-172.
4. Konno, H., Yamazaki, H. (1991). Mean-Absolute Deviation Portfolio Optimization Model and its Application to Tokyo Stock Market. *Menagement Science, Vol. 37.*
5. Le Sourd, V. (2007). *Performance Measurement for Traditional Investment.* Lille/Nice: EDHEC.
6. Modigliani, F., Modigliani, L. (1997). Risk-Adjusted Performance. *Journal of Portfolio Management, Vol. 23(2)*.
7. Pezier, J., White, A. (2006). The relative Merits of Investable Hedge Fund indices and of Funds of Hedge Funds in Optimal Passive Portfolios. *ICMA Centre Discussion Papers in Finance*. Henley Business School, University of Reading.
8. Tarczyński, W. (1994). Taksonomiczna miara atrakcyjności inwestycji w papiery wartościowe. *Przegląd Statystyczny, 3*, pp. 275-300.
9. Tarczyński, W. (1997). *Rynki kapitałowe. Metody ilościowe*, *Vol. II.* Warszawa: Placet.
10. Tarczyński, W. (2002). *Fundamentalny portfel papierów wartościowych.* Warszawa: PWE.
11. Tarczyński, W. (2009). O pewnym sposobie wyznaczania współczynnika beta na polskim rynku kapitałowym. *Studia i Prace Wydziału Nauk Ekonomicznych i Zarzadzania, 15*, pp. 199-213.
12. Watanabe, Y. (2006). Is Sharpe Ratio Still Effective? *Journal of Performance Meaurement, Vol. 11(1)*, pp. 55-66.
13. Wiesinger, A. (2010). Risk-Adjusted Performance Measurement – State of the Art, Bachelor. *Business, Economics.*
14. Wiśniewska, M. (2022). Wpływ pandemii koronawirusa (Covid-19) na zachowania inwestorów w świetle finansów behawioralnych. *Zeszyty Naukowe SGGW, Polityki Europejskie, Finanse i Marketing, 27(76)*, pp. 111-122.
15. Żebrowska-Suchodolska, D. (2017). Korelacja wskaźnika Sharpe'a z miarami będącymi jego uogólnieniem dla funduszy akcyjnych w latach 2004-2015. *Annales Universitatis Maria Curie-Skłodowska Sectio H - Oeconomia, Vol. 51(6)*, pp. 535-545.

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ASSESSMENT OF THE QUALITY OF TEACHER TRAINING IN THE AREA OF DIGITAL COMPETENCES

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Purpose: The purpose of this article is to point out the main directions for research quality education teachers in the area of digital competencies.
Design/methodology/approach: In content done analysis Letters indicators result in Politics Digital Transformation Education (PCTE) and proposals Validation competence digital.
Findings: Based on the analysis, we presented suggestions for defining digital teachers' competence levels. The solutions presented constitute proposal additions. Letters indicators result in Politics Digital Transformation Education (PCTE).
Originality/value: The article is of a nature overview.
Keywords: digital civilization, education, teachers' digital competencies.
Category of the paper: Literature review.

1. Introduction

One of the key challenges of modern civilization is to provide society with the opportunity to develop the competencies necessary to function efficiently in digital technologies.

Meeting the challenges related to the development of expected competencies includes several activities, among which the adaptation of the education system to current expectations is of great importance. Defining in 2006 and 2018, a catalog of critical competencies in the lifelong learning process (Recommendations, 2006, 2018) initiated a series of activities concerning modifying education systems and their adaptation to civilizational changes. This process continues uninterrupted, among others, due to permanent technological changes caused by introducing new solutions based on artificial intelligence and the need to protect against cyber threats.

The pace of development of competencies expected in society depends on changes in the education system. In recent years, work has been underway in Poland to describe activities aimed at adapting the way educational tasks are carried out to the requirements of modern times. Some of the essential documents that refer to this issue in our country are the Digital

Competence Development Program (PRKC, 2023) and the Digital Transformation of Education Policy (PCTE, 2024), which is a strategic document defining the state policy and planned activities undertaken in the area of digitization of education in the short term (until 2027), medium term (until 2030) and long term (until 2035). The document describes the coordination, planning, and evaluation principles of diagnosed and defined goals. The tasks and directions of action of all entities operating in the field of education have also been specified. The PCTE specifies the strategy and indicates methods and tools to achieve a fully digital education system in its assumptions. The most significant changes concern teaching methodology, which considers modern methods that support the development of students' creativity, digital competencies, and social competencies in an environment that uses the latest achievements in digital technology. It was considered necessary to shape the skills of responsible use of digital tools. Expectations towards teachers' competencies to carry out these tasks were clearly formulated. According to the authors, the PCTE identified ten areas that require intervention. These include (PCTE, 2024, pp. 29-56):

1. Evaluation of the state of digital education and the use of educational technology by students.
2. Change of the current core curriculum for preschool and general education.
3. New technologies, including artificial intelligence in school.
4. Teaching methods, digital didactics, digital teaching resources.
5. Teacher training and development.
6. Equipment for students, teachers and schools.
7. Educating digital professionals.
8. Digital Security.
9. Changing the organization of schoolwork.
10. Support for teachers and schools in the digital transformation process.

It is essential to emphasize the great value of the document in connection with the comprehensive approach to issues related to reforming education in Poland to adapt the entire system to civilizational change holistically. Attention was also drawn to the synergy of individual activities. It is worth emphasizing that among the listed areas was the preparation of teaching staff responsible for shaping key competencies, including students' digital competencies. In the face of the civilizational challenges facing Polish society, not only has the education of future teachers and their professional development undoubtedly become essential, but the method of verifying the effects of these activities has also become essential. After all, the efficiency of meeting contemporary educational challenges in the digital, constantly changing reality depends on the scope and level of teachers' digital competencies. Undoubtedly, the effects of introducing changes in education related to implementing the Digital Transformation of Education Policy (PCTE) depend on the quality of teachers' preparation.

2. Policy Digital Transformation Education (PCTE) – Challenges for education system

As mentioned, in September 2024, a resolution was adopted to adapt the Polish education system to contemporary civilization requirements. This resolution described the necessary actions to create conditions for the effective implementation of solutions included in the new core curriculum, EU documents, and other documents defining the strategy for the development of society in the digital era.

The most important part of the document (PCTE) consists of ten chapters (listed in the Introduction), which create a decalogue of actions exhausting the most critical areas requiring intervention. They address the issues most important for developing digital education and primary for the digital transformation of the school and the entire education system. An integral part of the document are the annexes (PCTE, 2024, pp. 128-166):

- Annex 1. Diagnosis.
- Annex 2. Action Plan.
- Annex 3. Schedule.
- Annex 4. List of result indicators.

Teacher education issues are described in detail in three areas:

- **New technologies, including artificial intelligence in schools** (area 3, PCTE, p. 30).
  The document paid particular attention to the presence of artificial intelligence in the life space of modern society and its impact on the activity of teachers and students. It was noted that the available solutions have specific educational values. Hence, they should be included in offering educational activities, developing skills in managing digital intelligent solutions (e.g., robot programming), and using currently widely available generative artificial intelligence (e.g., ChatGPT). The use of exemplary solutions in education will allow students to become familiar with the mechanisms of artificial intelligence, ways of using it, and the threats it can bring to human activity and life. It can also provide support for the teacher and help in the educational and personal development of the student, as well as in the organization of school work. Attention was drawn to the need to develop solutions that introduce these tools to educational institutions to benefit educational processes while minimizing the risk of threats and ethical violations. The need to introduce legislative regulations and educational support for teachers was also emphasized.
- **Teaching methods, digital didactics, digital teaching resources** (area 4, PCTE, p. 33).
  The document refers to the need to change the teaching methodology by moving from expository teaching to activating methods that prefer active learning using methods and means provided by digital technologies. It emphasizes the need to use the opportunities

created by technologies to support students in the process of constructing knowledge, especially in the case of special educational needs. In this environment, students learn through action, developing their skills, constructing their knowledge based on the knowledge they already have, and expanding it. When describing this model of learning, attention was drawn to research conducted in the field of cognitive psychology. Constructivism and constructionism are currently, especially in the technological environment, the leading concepts of students' cognitive development, making a significant contribution to how the development of their skills and competencies, especially digital ones and others, is perceived. The critical research in this area was conducted by Jean Piaget (individual constructivism), Lev Vygotsky (socio-cultural constructivism) (Mietzel, 2003, pp. 91-133; Klus-Stańska, 2010, pp. 263-285) and Seymour Papert (constructionism) (Papert, 1996). The priority assumption adopted by the researchers was the empowerment of the learner and the establishment of conditions that determine the effectiveness of the learning process. It was emphasized that the natural complement to these concepts is computational thinking, which defines the thought processes (ways of reasoning) accompanying the student when formulating problems and their solutions in a form that allows for their effective implementation using a computer, other digital technologies, as well as in an environment without technological support. The cited concept concerns the development of design thinking. At the same time, the issue of adapting digital didactics to young people with special educational needs is essential here, as well as taking into account the limitations that prevent participation in stationary education conducted in educational institutions. Attention was drawn to the need to develop and improve remote and hybrid education methods that can help overcome these limitations. In order to implement these concepts, it is necessary to provide all students and teachers with access to high-quality digital educational tools and resources. This approach must finally be officially introduced into educational policy in Poland. This need has been communicated for many years by many Polish educators, including Boleslaw Niemierko (1999), Dorota Klus-Stańska (2010), and Stanislaw Dylak (2000).

- **Teacher training and development** (area 5, PCTE, p. 37).
  Adequate preparation of teachers is crucial for the development of students' competencies, including, in particular, digital competencies. That applies to all teachers, regardless of the stage of education and the specialization they represent. The document emphasizes that "preparing teachers both to carry out classes by the applicable core curriculum of general education, as well as due to emerging new technologies and by the assumptions of universal education design related to the introduction of rational improvements" (PCTE, p. 8), is crucial for the development of students' competences in general, and digital competences in particular. The resolution refers to the regulation of the Minister of Science and Higher Education of July 25, 2019, on the standard of

education preparing for the teaching profession (Journal of Laws of 2024, item 453), specifying the scope of preparation of all teachers to use digital technologies, as well as teaching with their help. It was noted that the responsibility for the quality of implementation of this task rests with universities conducting teacher education. This task was considered crucial for implementing the digital transformation of education.

In conclusion, it should be emphasized that in addition to preparing new teaching staff for kindergartens and schools, the offer of universities in the field of teacher education should include various forms of professional development of teachers. This task was also entrusted to teacher development institutions. According to the provisions of the resolution, the state financially and organizationally supports it. It was emphasized that a good-quality development offer for teachers of all subjects in the area of using digital tools should be permanently available to interested teachers.

It is essential that it is up-to-date, responds to the needs and expectations of teachers, and also covers issues that change over time and are essential from the state's point of view, such as the impact of using technology on students' mental and physical health, cyberculture, digital citizenship, socialization in the digital world. In order to ensure the proper functioning of teacher education, close cooperation between the Ministry of Education and the Ministry of Science and Higher Education is necessary.

The presented characteristics of the assumptions contained in the resolution of the Council of Ministers: Digital Transformation Policy of Education, presented in the concept, constitute a coherent and internally complete document describing the actions that should be taken to introduce Polish education to the educational path of the 21st century. The entire strategy is based on an in-depth analysis of solutions already functioning in other countries and on a diagnosis of the current state of the Polish education system.

Teachers' education quality – critical criteria

Foreseeing a method of verifying the quality of implementing the tasks described in the assumptions is necessary. Therefore, the PCTE is supplemented by Annex 4, which contain*s the list of result indicators* and a description of the evaluation of the effects of the actions taken concerning, among others, education. Based on the description of the results, it should be assumed that the established indicators aim to verify the quality of the actions taken. Determining the quality of teacher education is an equally complex process as assessing the overall quality of education. In order to accurately assess whether teacher education is effective and of high quality, various aspects of professional preparation, competencies, and the effectiveness of educational processes should be taken into account. Determining the quality of teacher education requires a holistic approach that considers not only theoretical knowledge and pedagogical skills but also practical competencies, professional experience, and professional attitudes of teachers.

The critical criteria that help determine the quality of teacher education can be divided into two areas of activity: preparation for the teaching profession and professional development of in-service teachers.

Preparation for the teaching profession includes:

- the teacher training program, its scope and relevance, and the integration of theory and practice,
- methodological skills in relation to the latest achievements in pedagogy and psychology,
- professional internships and apprenticeships,
- external assessments and accreditations of teacher training institutions,
- the achievements of teacher education graduates measure the effectiveness of the educational process.

In turn, in the area of professional development of active teachers, the following are of crucial importance:

- teachers portfolio,
- commitment and pedagogical skills,
- mentoring support and creating professional networks consist of creating a support system and a platform for exchanging experiences for teachers.

There is no doubt, as emphasized above that the quality of a teacher's work is decisively influenced by having up-to-date pedagogical and psychological knowledge, methodological skills, and a high level of digital competencies that enable the implementation of educational tasks with students and support their learning process in the digital reality. Achieving such formulated effects requires high-quality education and improvement of teachers' competencies. It is also necessary to use objective forms of assessment of the knowledge possessed by teachers, e.g., by obtaining confirmation of obtained qualifications with appropriate certificates, micro-credentials, or authorizations. The lack of solutions in Polish education law that enable reliable certification of digital competencies possessed by teachers poses a severe risk of delays and difficulties in adapting the entire education system to the requirements of digital civilization.

3. List of indicators PCTE result and quality education teachers

One of the most basic standards, ISO 9000, officially defines quality. According to this definition, "quality is a certain degree of features inherent to a given product, which simultaneously meets the requirements of a specific group of recipients" (Rogala, 2014, pp. 536-545). Considering the expected level of teachers' digital competencies as a characteristic, the challenge becomes how to measure them.

In social research, the concept of evaluation is popularly used. It involves an objective assessment of a project, program, or policy at all stages, i.e., planning, implementation, and measurement of results. It should provide reliable and valuable information, allowing the knowledge acquired in this way to be used in the decision-making process. "Evaluation is a systematic study conducted using various methods, consisting of data collection, analysis, assessment, and reporting on results. Its aim is to estimate (in relation to clearly formulated criteria) the quality and value of the process and the effects of implementing public interventions" (Olejniczak, 2008, p. 22).

Considering the presented interpretations of the concepts of quality and evaluation, one should approach the proposals for assessing the effects of PCTE implementation described in Annex 4 with reserve, recognizing that at the stage of task implementation, this issue will be supplemented and expanded (Annex 4). Meanwhile, most of the indicators included in the document defining the level of implementation of the tasks included in it are based on self-assessment. The problem is that many indicators are based on declared data. For example:

3. New technologies, including artificial intelligence in school, p. 3	W3.2. Percentage of teachers declaring their ability to use artificial intelligence-based tools in teaching
4. Teaching methods, digital didactics, digital teaching resources, p. 5	W4.6. Percentage of teachers conducting compulsory education classes in primary or secondary schools who assess that their competencies in all areas of the DigCompEdu framework are at level B1 or higher
5. Teacher education and development, p. 6	W5.1. Percentage of graduates of teaching specializations who assess their competencies in all areas of the DigCompEdu framework as being at level B1 or higher

Some activities included in the schedule need to be evaluated. For example:

3. New technologies, including artificial intelligence in school	Development of examples of the use of artificial intelligence to prepare teachers to individualize work with students and conduct classes in their subject
4. Teaching methods, digital didactics, digital didactic resources	Development of digital teaching solutions
5. Teacher training and development	Development of a system for certifying the quality of training outcomes for teachers

From the point of view of social research methodology, this is the most subjective and, therefore, the least reliable method of collecting scientific data, often making it difficult to obtain reliable knowledge on the researched topic.

The declaration indicates low scientific value, while reliable verification of learning outcomes is essential. That involves examining the ability to apply knowledge according to B. Niemierka's Taxonomy of Educational Objectives ABC (Niemierko, 2002) and B. Bloom's Taxonomy of Educational Objectives (Armstrong, 2010).

4. Rate quality education - level obtained/possessed competence – proposal research

Competencies should be understood as dispositions regarding knowledge, skills, and attitudes that allow tasks to be performed appropriately (Filipowicz, 2014). Digital competencies, conversely, are understood as a harmonious composition of knowledge, skills, and attitudes that enable living, learning, and working in a digital society (using digital technologies). The most crucial thing in this respect is the relationship between competencies and the tasks performed, and these tasks may be related to the performance of various social roles. The case article refers to the role of a teacher.

A key role in assessing competencies is played by defining behavioral indicators of isolated competencies, which are defined as observable behaviors that allow for the identification and assessment of the occurrence of a given competency in an individual (Filipowicz, 2014). In order to properly conduct teacher competency research, it is necessary to develop a competency profile covering the scope and level of competencies necessary/desirable in the teaching profession. In practice, competency profiles are used, among others, to design career paths, assessment and development activities. That allows for the definition of a competency model containing a list of competencies with their names and definitions, an observational scale, development guidelines, questions for a competency test, and questions for a qualification interview (Filipowicz, 2014).

The essential feature of social research is that it is a carefully designed procedure subject to rigorous analysis. Progress depends on the results of research using appropriate methods. The choice of method depends on the specificity of the researched object (e.g., the number of people studied) and the situation (where and in what conditions the research is carried out). This choice is superior to the choice of technique and tools. Proper preparation for research should include research objectives, the subject of research, formulated research problems, the choice of method, technique, and research tools, determining the research area, and defining the research sample (Krajewski, 2020, pp. 59-110).

It should be remembered that in social research, one of the most critical assumptions is that the researcher maintains research objectivity. Objectivity is a research attitude free from prejudice and a way of presenting results without taking one's own position on them. It is also worth referring here to the credibility of the obtained results. The selection of applied methods and research tools influences research objectivity. Various sources and perspectives should be used to ensure that the obtained research results are not influenced by a single point of view. That allows for objectively assessing the variables studied and determining their value.

In the case of digital competencies, the most objective verification of the competencies is their certification, obtaining a micro-credential, or confirming new authorizations. The most appropriate instruments for certification (certifying the possession of the expected level of

competence) are standardized tools verified in terms of validity and reliability, developed based on adopted standards. In the case of digital competencies, the DigCompEdu standard has currently been adopted . A feature of these tools is their objectivity in assessing competencies. The research methods used must meet the criterion of validity and reliability. It is best if they are standardized. The validity of a research method consists in determining the degree of compliance with which a measurement tool measures what it was designed to measure. It is related to the question of whether researchers managed to measure what they planned to measure (Stanisz, 2007, p. 435).

On the other hand, reliability measures the extent to which the test result reflects the test feature's actual value and to what extent errors of various origins distort it (Brzyski et al., 2010, p. 694). In order to broaden the spectrum of competence verification, self-assessment and assessment by a superior can be additionally used. That is the absolute minimum referred to as a 180-degree assessment. Additional assessments from other perspectives, 270 degrees or a 360-degree survey, allow for a broader and more reliable assessment (Jezierska, pp. 253-272). The obtained results may be burdened with a subjective error depending on the intentions of the people tested.

A way to identify variables (e.g., digital competencies necessary in the teaching profession) is to conduct a qualitative study among experts using the focus group interview method. The result of work in an expert team may be a set of characteristic digital competencies described using definitions and behavioral indicators, as well as a behavioral observation scale selected to assess these competencies, or more precisely – a developmental scale. All experts must accept the developed set of competencies. In this way, a list of teachers' digital competencies can be determined (Table 1). The digital competencies adopted for implementation can be determined using documents (e.g. DigCompEdu, PCTE).

Table 1.
Examples of characteristics of teachers' distinguished digital competencies

Social role	IT skills	Information and communication skills	Functional competencies
Teachers of various levels of education and specializations (preschool, early school education, grades IV-VII, secondary education)	- knowledge of digital tools and their use in designing and implementing educational situations	- use of data sets in the educational process, - managing an educational project in a digital environment, - identifying and counteracting cyber threats	- developing students' digital competencies related to learning

Source: Own study based on expert opinion[1].

[1] An expert opinion defines digital competences specific to various social roles and indicates measurement methods. It was developed by the Polish Information Processing Society Team, which included the author. That is unpublished material. The proposed model for assessing digital competencies uses the 180-degree method. The content presented in the article presents a modified version of the model that is included in the expert opinion.

The division of digital competencies was adopted by *the Framework Catalogue of Digital Competences* (Jasiewicz et al., 2018).

Below is an example description of one of the teachers' digital competencies listed in Table 1 (Table 2).

Table 2.
Characteristics of teachers' digital competence EDUCATIONAL PROJECT MANAGEMENT IN THE DIGITAL ENVIRONMENT

Category	Description
Name	EDUCATIONAL PROJECT MANAGEMENT IN THE DIGITAL ENVIRONMENT *(information and communication competence)*
Definition	Knowledge of the possibilities of functioning in a digital environment. Knowledge and ability to apply project methods in educational processes using IT. Ability to manage a project using IT tools.
Indicators Behavioral	- Plans educational projects in the digital environment. - Chooses a digital environment focused on project management. - Uses IT tools to manage student projects.

Source: Own study based on expert opinion.

The research resulted in developing a proposal for research tools that could be used to measure the level of digital competence of teachers indicated by experts. In relation to the specific digital competencies of teachers, the research recommended a measurement method in the form of teacher self-assessment and observation of teacher behavior by the supervisor. Therefore, a self-assessment sheet (Table 3) and a supervisor assessment sheet (Table 4) of the level of digital competencies based on a scale from A to E were proposed.

Example of a teacher's self-assessment scale for digital competencies:

A. You do not exhibit the desired behaviors associated with a given competency. You make mistakes and need help coping with tasks that require a given competency.
B. You try to behave in the expected way to cope with tasks that require certain competencies. You still make mistakes, but you learn from them.
C. You are independent. You correctly perform most standard tasks that require a given competency. You need help with slightly more difficult tasks, so you make mistakes in new, non-standard situations.
D. You efficiently and flawlessly perform most tasks that require a given competency. You also cope with difficult tasks in non-standard situations. You demonstrate positive behaviors that describe a given competency. You are often held up as a role model for others. You indicate and explain expected behaviors to others.
E. You perform even challenging tasks that ideally require a creative approach to a given competence. You demonstrate a high level of automatism in the actions you perform, as well as new behaviors within a given competence. You set tendencies and trends in a given area.

Below is an example of self-assessment of the level of the proposed competence MANAGEMENT OF AN EDUCATIONAL PROJECT IN A DIGITAL ENVIRONMENT.

Table 3.
Example of self-assessment of the level of the proposed competence EDUCATIONAL PROJECT MANAGEMENT IN THE DIGITAL ENVIRONMENT

Behavioral indicators	Sample survey questions	AND	B	C	D	E
Chooses a digital environment focused on project management	- I distinguish between project management software. - I select digital tools to run projects.					
Plans educational projects in the digital environment	- I am preparing a scenario for an educational project in a digital environment. - I am preparing digital educational materials for a project in a digital environment.					
Uses ICT tools to implement projects	- I prepare a project implementation schedule using applications such as Padlet, Gantt, MS Project. - I present teaching material using IT in design classes.					

Source: Own study based on expert opinion.

An example scale for assessing teachers' digital competencies by their supervisor could include the following levels:

A. There are no desirable behaviors associated with a given competency. The employee makes mistakes and is clearly unable to cope with tasks requiring a given competency.
B. The employee behaves expectedly to cope with tasks requiring the given competencies. He still makes mistakes but learns from them.
C. Independent employee. Correctly performs most standard tasks requiring a given competency. He has problems with slightly more difficult tasks, so he makes mistakes in new, non-standard situations.
D. Efficiently and flawlessly performs most tasks requiring a given competency. Also copes with difficult tasks in non-standard situations. Demonstrates positive behaviors describing a given competency. It is often held up as a role model for others. Indicates and explains expected behaviors to others.
E. Perfectly performs challenging tasks that require a creative approach to a given competency. Demonstrates a high level of automatism in the actions performed and new behaviors within a given competency. Sets trends and tendencies in a given area.

Table 4.
Example *of the Questionnaire for the assessment of teachers' digital competence by the superior* **-** *MANAGEMENT OF AN EDUCATIONAL PROJECT IN THE DIGITAL ENVIRONMENT*

Behavioral indicators	Sample survey questions	AND	B	C	D	E
Chooses a digital environment focused on project management	- Distinguishes project management software. - Select digital tools for project management.					
Plans educational projects in the digital environment	- Prepares a scenario for an educational project in a digital environment. - Prepares digital educational materials for a project in a digital environment.					
Uses ICT tools to implement projects	- Prepares a project implementation schedule using applications such as Padlet, Gantt, MS Project. - Presents teaching material using ICT in design classes.					

Source: Own study based on expert opinion.

5. Summary

The draft resolution of the Council of Ministers - Digital Transformation Policy of Education describes an essential policy of digital transformation of education from the point of view of the development of the information society in Poland. It comprehensively covers several activities to prepare the young generation to function in the digital reality. Its assumptions at the level of strategy are optimistic. However, the most challenging task is to ensure the quality of the actions taken to achieve the intended effects in a coherent and harmonious manner. Therefore, planning indicators are already at the stage of planning specific projects, based on which it will be possible to assess the level of task implementation. Thanks to this, verifying whether the intended effects have been achieved will be possible.

References

1. Armstrong, P. (2010). *Bloom's Taxonomy. Vanderbilt University Center for Teaching*. Retrieved from: https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/, 20.10.2024.
2. Brzyski, P., Knurowski, T., Tobiasz-Adamczyk, B., (2003). Validity and reliability of the general health assessment questionnaire SF-20 in the elderly population. *Przegląd Epidemiologiczny, No. 57.*

3. *Council Recommendation of 22.05.2018, on key competencies for lifelong learning (Text with EEA relevance) (2018/C 189/01).* Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018H0604(01)&from=en.
4. *DigCompEdu*. Retrieved from: https://joint-research-centre.ec.europa.eu/digcompedu_en, 10.09.2024.
5. Digital Competence Development Program. *Resolution No. 24 of the Council of Ministers* of 21.02.2023, on the establishment of a government program called the "Digital Competence Development Program" (MP item 318). The document is available on the Digital Competences website - Ministry of Digital Affairs - Gov.pl Portal (www.gov.pl).
6. Dylak, S. (2000). Constructivism as a promising perspective of teacher education. In: H. Kwiatkowska, T. Lewowicki, S. Dylak (Eds.), *Modernity and teacher education*. Warszawa: WSP ZNP.
7. Filipowicz, G. (2014). *Competency management. Corporate and personal perspective.* Warszawa: Wolters Kluwer.
8. Jasiewicz, J., Filiciak, M., Mierzecka, A., Śliwowski, K., Klimczuk, A., Kisilowska, M., Zadrożny, J. (2018). *Framework Catalog of Digital Competences.* Retrieved from: https://www.gov.pl/web/cppc/skalowanie-dobrych-praktyk.
9. Jezierska, J. (2019). Employee evaluation system as an instrument of human resources management. *Konin Socio-Economic Studies, 4/5*.
10. Klus-Stańska, D. (2010). *Didactics in the face of the chaos of concepts and events*. Warsaw: Wydawnictwo Akademickie ŻAK.
11. Krajewski, M. (2020). *On the methodology of science and the principles of scientific writing.* Płock: WN NOVUM.
12. Mietzel, G. (2003). *Psychology of education. A practical handbook for pedagogues and teachers.* Gdańsk: Gdańskie Wydawnictwo Psychologiczne.
13. Niemierko, B. (1999). *Between school assessment and didactics. Closer to didactics*, Warsaw: WSiP.
14. Niemierko, B. (2002). *School assessment without secrets*. Warsaw: School and Pedagogical Publishing House.
15. OECD (2019). *OECD Skills Strategy Poland: Assessment and Recommendations, OECD Skills Studies.* Paris: OECD Publishing. Retrieved from: doi: https://doi.org/10.1787/b377fbcc-en.
16. Olejniczak, K. (2008). Introduction to evaluation issues. In: K. Olejniczak, M. Kozak, B. Ledzion (Eds.), *Theory and practice of evaluation of public interventions. Academic textbook*. Warszawa: Wydawnictwa Akademickie i Profesjonalne.
17. Papert, S. (1996). *Brainstorming. Children and computers.* Warszawa: PWN.
18. Policy Digital Transformation Education (2024). *Resolution No. 98 the Council of Ministers* of 12.10.2024. Retrieved from: https://dziennikustaw.gov.pl/M2024000081 201.pdf

19. *Recommendations Parliament European and of the Council of 18.12. 2006, on competence key in the process learning myself By whole life* (2006/962/EC). Retrieved from: https://eur-lex.europa.eu/legal-content/PL/TXT/PDF/?uri=CELEX:32006H0962&from =LT.
20. Rogala, P. (2014). Continuous quality improvement according to ISO 9000 series standards. *Scientific Works of the Wrocław University of Economics, No. 340*, pp. 536-545.
21. Stanisz, A. (2007). *Accessible statistics course using STATISTICA PL on examples from medicine. Volume 3: Multivariate analyses.* Kraków: StatSoft.

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EMPLOYEE EXPECTATIONS AND NEEDS REGARDING EMPLOYEE APPRAISAL: ANALYSIS AND RECOMMENDATIONS

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Purpose: The aim of this article was to develop principles that should characterize the employee evaluation process to ensure it is effective, fair, and acceptable to employees.
Design/methodology/approach: In the paper the following methods were applied: desk research, literature analysis, targeted survey, expert interviews.
Findings: Effective employee evaluation requires a holistic approach that considers employee needs and expectations, fosters transparent and fair criteria, supports professional development, and emphasizes open communication, healthy relationships, and two-way constructive feedback.
Originality/value: The development of eight news principles that should characterize the process of employee appraisal.
Keywords: Employee Appraisal, Performance Evaluation, Human Resource Management.
Category of the paper: Research paper.

1. Introduction

Contemporary organizations operate in a dynamically changing environment (Nudurupati et al., 2021; Wybrańczyk et al., 2018) where efficiency and adaptability are key success factors (Naveed et al., 2022). In this context, employee evaluation systems must be appropriately designed to not only measure performance but also support the development of competencies and adapt to the individual needs of employees (Stofkova, Sukalova, 2020).

The traditional approach to employee evaluation often focuses primarily on employee performance results (Meijerink et al., 2022; Murphy, 2020). However, in recent years, there has been a shift towards more holistic and diverse evaluation methods that consider various aspects of employee activity. Currently, there is an increasing emphasis on assessing soft skills, such as communication (Kotamena et al., 2020), teamwork (Trzeciak, Banasik, 2022),

leadership (Rohmatunnisa, 2021), adaptability (Van Dam, Meulders, 2020), and innovation (Thneibat, Sweis, 2023). This approach stems from a growing awareness that organizational success depends not only on hard results but also on organizational culture and employees' interpersonal skills.

Employee evaluation also holds significant importance from the perspective of motivation and engagement. Regular and constructive feedback helps employees understand their strengths and areas for improvement (Murphy, 2020), which in turn influences their professional development and job satisfaction. Properly conducted evaluations can act as a motivator, encouraging employees to achieve higher performance and engage in organizational activities. On the other hand, an improper approach to evaluation can lead to frustration, decreased morale, and employee turnover.

Contemporary research indicates several key elements that are crucial for effective employee evaluation. As noted by Jiang and Shen (2023), transparency in the evaluation process is one of the most important aspects, influencing the perception of fairness and trust in the system. Employees need to have clarity regarding the evaluation criteria, methodology, and the goals set by the organization (Baird et al., 2020). The regularity and frequency of evaluations also play a significant role. Murphy (2020) points out that annual evaluations are often insufficient for effectively managing employee performance and development. Increasingly, it is recommended to use more frequent, less formal feedback sessions that allow for continuous action adjustments and support employee development (Dangol, 2021).

Another important aspect is the bidirectional nature of the evaluation process. Employees should have the opportunity to actively participate in the process, sharing their insights, expectations, and needs. Such interaction enhances engagement and fosters a sense of shared responsibility for personal development. Including employees in the evaluation process also contributes to building a more open and transparent organizational culture, where feedback is regarded as a developmental tool rather than a control mechanism.

Employee evaluation methods are constantly evolving, reflecting organizational and technological development as well as the evolution of approaches to human resource management. Traditional evaluations, such as annual or quarterly reviews, have been the standard for decades (DeNisi, Murphy, 2017). Regular performance reviews focusing on achieving operational and financial goals facilitate strategic planning and are relatively simple to implement. However, critics point to their limited adaptability in dynamic work environments and the risk of delayed responses to employee issues (Gruman, Saks, 2011; Trzeciak, 2020). Research indicates that infrequent evaluations can lead to reduced employee satisfaction and demotivation, as they fail to address the organization's current needs (Shuck et al., 2018).

Multisource methods, such as the 360-degree evaluation, have gained popularity due to their comprehensiveness. Feedback is gathered from various sources: supervisors, colleagues, subordinates, and clients (Bracken, Rose, 2011). Research by Fleenor et al. (2020) demonstrates

that this method enhances employee self-awareness and promotes the development of interpersonal skills. However, its implementation can be costly and time-consuming, and the lack of anonymity may lead to biases in evaluations (Colquitt, LePine, Wesson, 2013).

Competency-based methods, such as Behaviorally Anchored Rating Scales (BARS), focus on specific behaviors critical to effective job performance. These scales aid in clearly communicating expectations and standardizing evaluations (Martin-Raugh et al., 2016). However, their development and regular updates require substantial resources (Gupta, Shaw, 2014).

Quantitative methods include approaches such as employee comparisons and forced distribution. Ranking employees allows for the elimination of central tendency bias in evaluations but may lead to competition rather than collaboration (Ahmed et al., 2013). On the other hand, the forced distribution method requires assigning a specific percentage of employees to various performance categories, which can result in artificially lowered ratings and reduced team morale (Kan, Tsai, 2022).

Qualitative methods, such as the critical incident method, allow for documenting key employee behaviors that impact job performance. They provide detailed information but require systematic and accurate monitoring (Fekete, Rozenberg, 2014).

Modern technology-based methods include employee evaluation IT systems as well as data analytics and artificial intelligence. IT systems enable real-time performance monitoring and the provision of continuous feedback, enhancing the efficiency of evaluations but raising concerns about privacy and excessive monitoring (Bhave, 2014; Tomczak et al., 2018). Data analytics, on the other hand, facilitates the identification of potential talents, but its application requires caution to avoid overreliance on algorithms without considering the human context (Minbaeva, 2018).

Participatory methods, such as self-assessment and peer evaluation, foster employee engagement and support a culture of feedback (Panadero et al., 2016). However, their effectiveness depends on the level of trust within the organization and clearly defined evaluation guidelines.

Mixed methods, such as 180-degree evaluations and observational assessments, combine various approaches to enable a more comprehensive performance analysis. The 180-degree evaluation, limited to supervisors and subordinates, is easier to implement than multisource methods (Das, Rajini, 2023).

Despite significant advancements in evaluation methods, the literature still lacks a consistent approach to continuous employee assessment. Traditional evaluation systems, even those leveraging modern technologies, are often conducted at designated intervals, such as quarterly or annual reviews (DeNisi, Murphy, 2017). Continuous assessment, defined as the process of providing ongoing, real-time feedback, offers a potential solution to many challenges, such as delayed responses to issues or a lack of flexibility in dynamic work environments (Pulakos et al., 2015; Szumiec, Trzeciak, 2024).

Although IT systems and data analytics are beginning to introduce elements of continuous monitoring, there is still a lack of research evaluating the impact of such practices on employee engagement, motivation, and long-term development. There is also a gap in understanding how to adapt these systems to different organizational cultures (Jończyk, Buchelt, 2015) and how to minimize the risks of excessive monitoring (Lin, Kellough, 2019), which can lead to a loss of employee trust (Mulvaney, 2019). Advancing research in this area is crucial to fully realizing the potential of continuous assessment in modern organizations.

2. Methods

The aim of this article is to develop principles that should characterize the employee evaluation process to ensure it is effective, fair, and acceptable to employees. The study seeks to identify key elements that can enhance the efficiency and acceptance of evaluation systems in organizations.

Despite extensive research on employee evaluation, there is a lack of consistent guidelines on the principles that should govern the evaluation process in modern organizations. Existing studies primarily focus on tools or technical methods but rarely offer a holistic approach that incorporates employee perception, behavioral aspects, and practical tools to support the evaluation process, such as ready-made forms, anonymous systems, or advanced technologies.

Moreover, there is a shortage of analyses in the literature regarding the impact of elements such as transparency, constructive feedback, or the absence of negative consequences on the effectiveness and acceptance of evaluation systems. This gap highlights the need to develop a comprehensive set of principles that could serve as guidelines for organizations implementing or modernizing their evaluation systems.

This study addresses this gap by providing a cohesive and practical set of principles that can contribute to improving the quality of employee evaluation processes in organizations.

In order to reach the main research goals, two series of interviews were conducted. The first series consisted of structured interviews with six experts from various fields, including: an IT Project Manager, an HR Department Director, an R&D Projects Director, a University Professor whose primary research focuses on employee evaluation processes, an Engineering Project Manager, and a Corporate Employee. The purpose of that interview was to consult the main assumptions and conclusions the authors came up with as a result of the literature review. The second interview series took the form of online surveys, that was distributed among managerial workers cooperating with the Silesian University of Technology and it's employees, as well as among part-time students who occupy various positions, and are professionally active. The main objective of the study was to identify the needs, expectations

and attitudes towards the employee evaluation process. The total number of participants in the second series was 91 respondents. At a assumed confidence level of alpha equal to 0.05, the sample error should not exceed 10%.

The first 20 questions in our survey were build by using a five-point Likert scale (ranging from "strongly agree" to "strongly disagree"). To analyze the responses the selected options were converted into numerical values. The transformation process of the scale was carried out as follows:

- "Strongly agree" was converted to a value of 1.
- "Agree" was converted to a value of 0.5.
- "Neither agree nor disagree" was converted to a value of 0.
- "Disagree" was converted to a value of -0.5.
- "Strongly disagree" was converted to a value of -1.

After converting the responses into numerical values, descriptive statistic for each question were calculated. The mean values of the Likert scale responses provide an understanding of the overall attitude of the respondents towards each statement in the survey. The mean values can range from 1 (indicating strong agreement) to -1 (indicating strong disagreement), with a value of 0 indicating a neutral stance or lack of a clear opinion from the respondents.

The survey also included 6 multiple-choice questions where respondents selected the options they considered best for a given topic. For these questions, the percentage of all respondents who selected each option was calculated. Those indicate the proportion of respondents who favored each option, allowing for the identification of the most and least popular choices among the respondents.

This transformation and analysis allowed for the quantitative representation of qualitative data collected in the survey, facilitating further statistical analyses and interpretation of the research findings.

3. Results

3.1. Overall characteristics of the respondents group

The respondents group consisted mainly (37.36%) of employees who's professional position was described as an Specialist, Foreman or master of crafts. The second largest fraction were managers (28.57%) – whereby 12.09% are lower level managers, and 16.38% middle-level manager. The remaining 34.07% consisted of various and singular cases of worker occupations, with the mention worthy exception of two (2.2%) company presidents. When it comes to professional experience the majority (57.14%) of respondents has little professional experience (less than 3 years), and the second frequently (25.27%) chosen answer

was 3 to 6 years of experience. This is tightly related to the age of respondents, who in most cases (68.13%) were 30 or younger. It is worth mentioning that the size of companies in with the respondents were employed covers all organizational sizes: 30.77% work in corporations with more than 1000 workers, 16,48% in large companies (250-999 workers), 23.03% in medium sized organizations (50-249), 15,38% in small companies (10-49), and the remaining 14.29% in micro companies (less than 10 employees).

The respondents represented a wide variety of work sectors, what is visualized in Figure 1.

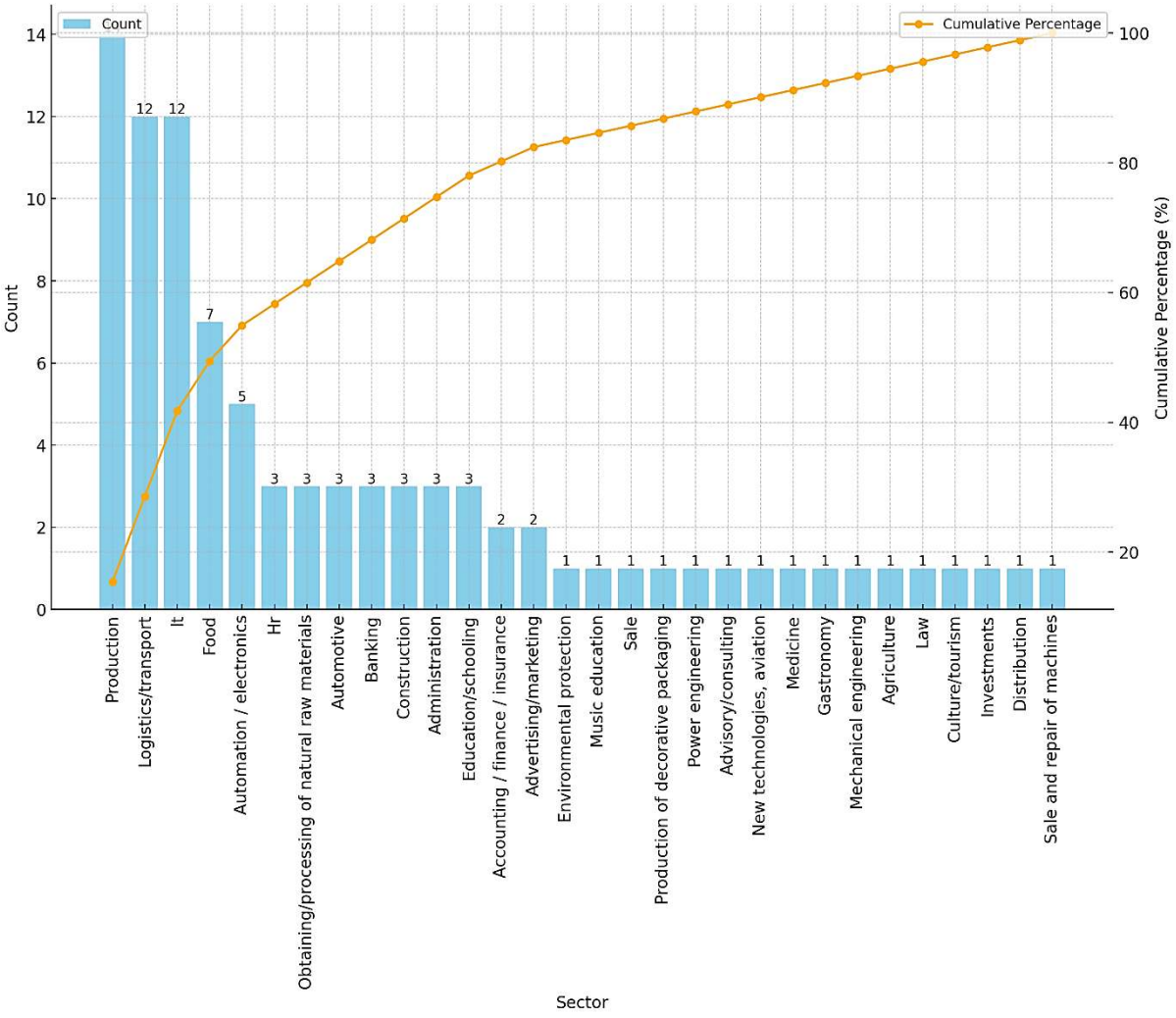

Figure 1. Count and cumulative percentage share of sectors represented by the survey respondents. Source: Own work.

The presented sample group should offer a comprehensive overview on how employees perceive the evaluation process, because it includes perspectives from various work environments, and at the same time, because the sample focuses on younger employees it should offer an insight into how todays and future workers will approach the evaluation process.

3.2. Survey results

As mentioned before, the survey contained 20 Likert scale questions related to the concept of employee assessment. The distribution of answers chosen by the respondents and the mean value for each question were shown in Figure 2.

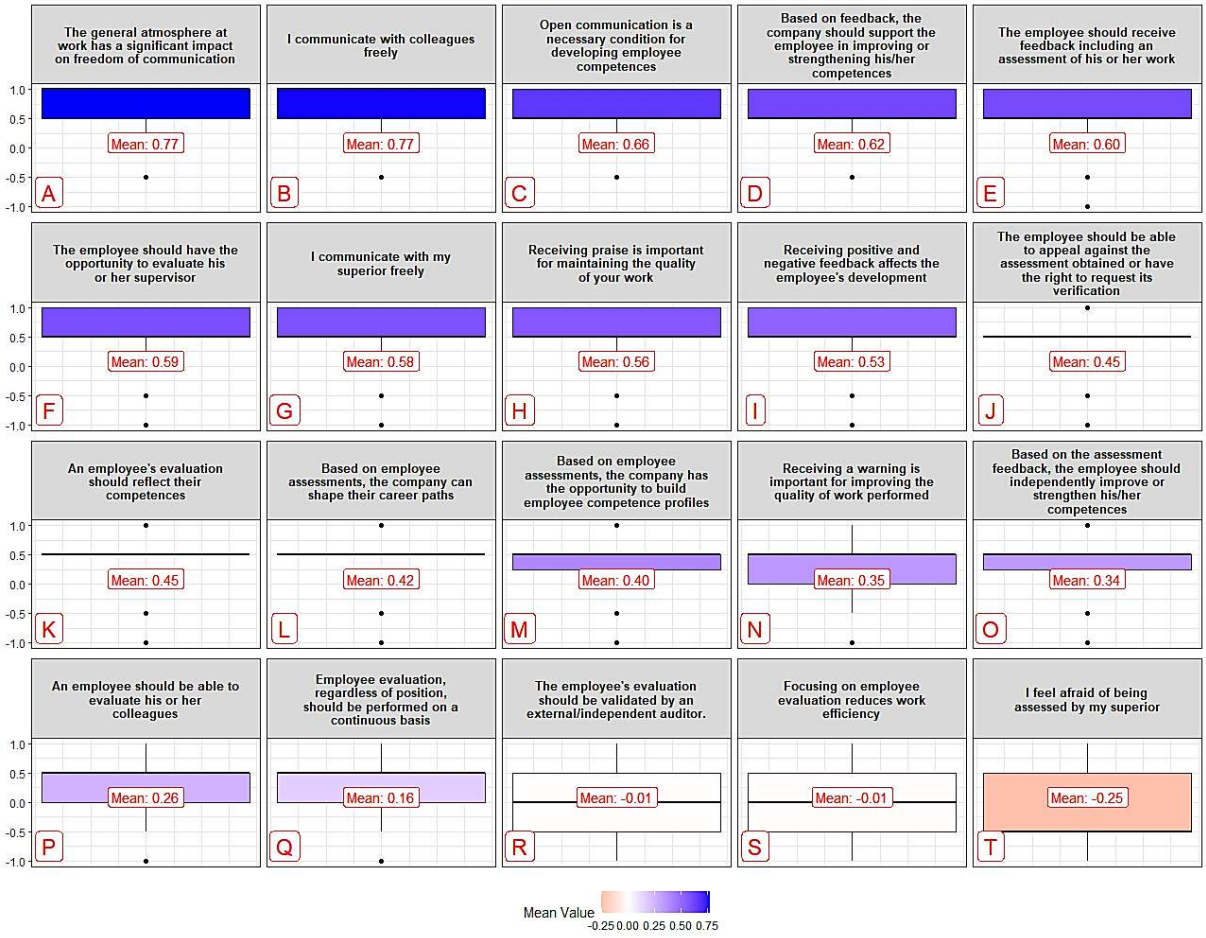

Figure 2. The distribution of answers and the mean value of responses given by the respondents to questions regarding their attitudes towards employee assessment.

Source: Own work.

As one can read, for the majority of questions the responses expressed strong or medium strong agreement with the presented statements. The only clear disagreement concerned the statement "I feel afraid of being assessed by my supervisor" ("T" panel in figure 2). The calculated mean value of answers is -0.25, and 50% of all answers were in the range of -0.5 to 0.5. This indicates that most of employees are not intimidated by the assessment process.

The respondents gave most varied responses to questions from panels "S" and "R", with mean value nearly equal to 0. Many employees are somewhat skeptical with the idea of external auditors evaluating their performance, with is understandable as it introduces uncertainty – they do not know the assessor. The second question reveals, that just as meany employees are affected negatively by focusing on their evaluation, as there are not. The reasons

for that distinction might have various sources; from personality traits (insecure, anxious, self confident, etc.) to the work environment itself (does the evaluation interfere with the ordinary work schedule, does the assessment create stressful atmosphere).

The questions from panels from “A” to “I” were all characterized by high mean values, witch translates to responding with either “I strongly agree” or “I agree”. Questions “A”, “B” “C” and “G” refer in general to open and not restricted communication within a company – concerning overall atmosphere, as well as the relationship with colleagues and superiors. Next, the highly positive response rate to questions “D” and “C” again highlight the importance of competence development through open communication and feedback. Furthermore, the crucial role of feedback (foremost positive) was expressed in questions “E”, “H”, “I”. Whereby in question “F” the respondents underlined they expect that the evaluation should be mutual and should be allowed to produce feedback for the supervisors as well.

The least versified answers were given to questions “J”, “K” and “L”, to with nearly all respondents replied with “I agree”. They reflect the employees expectations of fair assessment and career development based on competences.

Similarly to previous cases, the responses to questions “M”, “N” and “O” were mainly “I agree” but were more diversified, and some participants of the study replied to them with "Neither agree nor disagree". This indicates some level of uncertainty among employees regarding the possibility of achieving positive outcomes through negative feedback, as well as some skepticism among some employees when it comes to building competence profiles based on the outcomes of an assessment.

Finaly, the rather slightly positive character of answers given to questions “P” and “Q” indicate, that the concept of continuous and mutual among colleagues assessment process has potential to be applied, but would require employee preparation and time for accommodation.

The so far presented results indicate that the highest-rated aspects of worker evaluation primarily should focus on communication, constructive feedback, and transparency.

The last 6 questions were meant to identify what would engage employees in the process |of evaluation and what would make it easier, considering tree main evaluated groups: employees (subordinates), co-workers, and superiors. The obtained results were visualized in Figures 3 and 4.

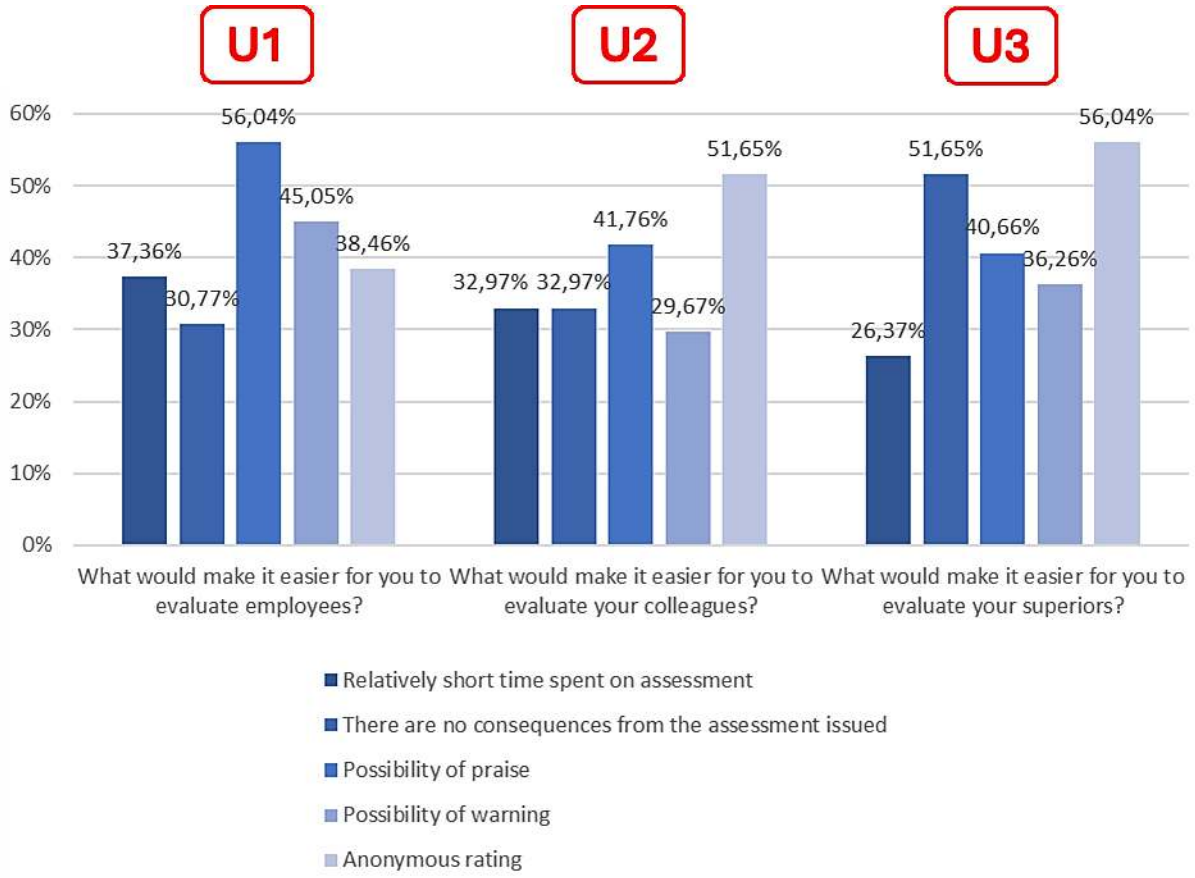

Figure 3. The share of selected options that would make the process of evaluating subordinates, co-workers, and supervisors easier in the opinion of survey respondents.

Source: Own work.

The obtained results indicate that there are differences in evaluation depending on the hierarchical relationship between the assessor and the assessed. When it comes to evaluating superiors (panel U1 in figure 3), most of the respondents (56.04%) pointed out that anonymity would make it easier for them to asses their supervisors. The second most commonly selected option (51.64%) was "there are no consequences from the assessment". Those two options suggest that in order to receive a honest grade of a supervisor's performance from employees, they require some insurance, that their opinion will not cause retaliation. Similarly, most (51.65%) of the respondents have underlined anonymity as the key aspect for assessing their coworkers (panel U2 in figure 3). Whereby the second commonly (41.73%) chosen option indicated that the possibility for giving positive feedback, would make it easier to do this. Interestingly, the same option was the most popular choice (56.04%) when the respondents were considering the assessment of subordinates (panel U3 in figure 3). At the same time, only for this relationship combination the possibility of giving a warning to a employee was the second common choice (45.05%). Overall the results indicate that employees expect the evaluation process should allow to produce constructive feedback, as well as that it is mutual and fair.

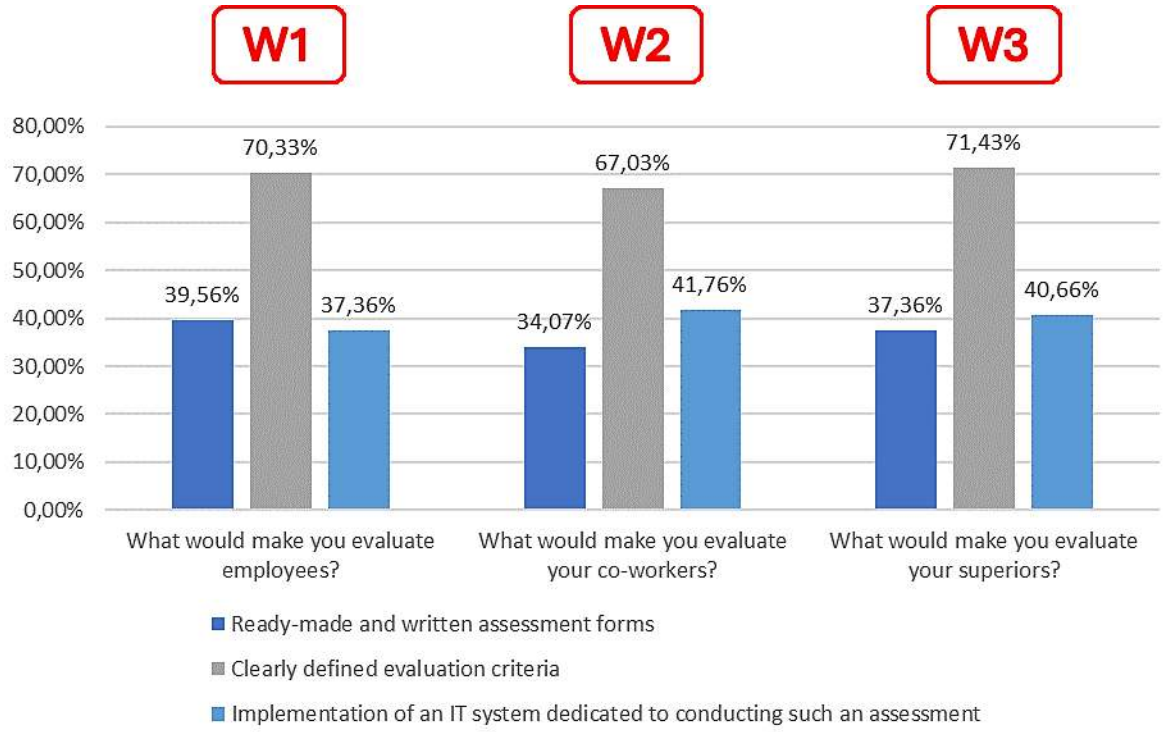

Figure 4. The share of selected options that would make workers to evaluate their subordinates, co-workers, and supervisors.

Source: Own work.

The results shown, in figure 4 clearly show that, no matter the hierarchical relationship between the assessor and the assessed, clearly defined evaluation criteria are the most important aspects that would encourage the respondents to perform an evaluation. When it comes to other amenities, over a third of respondents (39,56%) say that ready-made forms would ease the process. The reason for this might be, that a superior needs to asses more people, than a subordinate would. On the other hand, IT systems, were selected by approximately 40% of respondents, as an option that would encourage them to asses their co-workers and supervisors. The main observation that can be made from the presented results, is that the evaluation process should be simple and practical.

4. Discussion

Based on the identified in the survey key aspects of employee evaluation on can derive from them principles that might be applied in organizations in order to encourage employees to willingly and without concerns participate in the evaluation process. The derived principles are presented in Table 1.

Table 1.
The main principles for employee evaluation the emerged from the conducted research

Question symbol	The deriving principle	Explanation
C, D, L, M	Approach Based on Competences	The role of both praise and constructive criticism in maintaining work quality suggests a principle focused on competences. This principle ensures that employees are continually developing and improving their skills.
W1, W2, W3	Practicality and Simplicity	The emphasis on making the evaluation process quick, without negative consequences, and anonymous suggests the principle of practicality and simplicity. This principle ensures that evaluations are easy to perform and encourage honest feedback.
A, B, G, J, P, R, T, U1, U2, U3	Reciprocity and Fairness of Assessment	The value placed on employees' ability to evaluate their supervisors and appeal assessments reflects the need for reciprocal and fair assessment processes, ensuring that all voices are heard and assessments are just.
O, Q	Iterative Approach	Emphasizing a cyclical process that encourages continual reassessment and improvement based on feedback, ensuring the evaluation system evolves and adapts to changing needs.
C, E, H, I, N, S, U2, U3	Constructive Feedback	The emphasis on the necessity of regular, supportive feedback for improving competences indicates the importance of constructive feedback as a principle for employee development.
B, E, G, J	Open and Transparent Information Flow	The importance of free communication with colleagues and superiors, and a supportive work atmosphere, highlights the need for transparent information flow within the organization.
L, M, O, Q	Targeted on Continuous Improvement	The focus on clearly defined criteria, ready-made forms, and the implementation of IT systems indicates a principle geared towards continuous improvement. This principle ensures that the evaluation process is structured, fair, and facilitates ongoing development.
D	Stable and Balanced Development	Ensures a balanced approach to employee growth, addressing both immediate performance and long-term career development needs.

Source: Own work.

The presented principles were arranged in order to create an easy to remember acronym – APRICOTS.

An Approach Based on Competences forms the foundation of modern employee evaluation systems. The literature emphasizes that focusing on professional competences enables more effective talent management and individual employee development (DeNisi, Murphy, 2017; Liebert, Trzeciak, 2016). Both technical and interpersonal competences are critical for organizational effectiveness, as confirmed by the research of Jiang and Shen (2023). It is essential for an evaluation system to identify both the strengths of employees and areas requiring improvement. As noted by Fleenor et al. (2020), competency-based systems contribute to more personalized career development planning, thereby supporting engagement and motivation in the workplace.

The Practicality and Simplicity principle is crucial for the acceptance of the evaluation process. As noted by Gruman and Saks (2011), simple evaluation systems are more effective and more readily accepted by employees. Research findings indicate that respondents prefer straightforward tools, such as ready-made forms and anonymous evaluation systems. Similar

conclusions are presented by Fleenor, et al., 2020, who emphasize the importance of simplicity in multi-source processes.

Ensuring the Reciprocity and Fairness of Assessment is a key element in building trust within an organization. As highlighted by Colquitt, et al., (2013), transparent criteria and the possibility of two-way feedback enhance employees' perception of fairness. Survey respondents emphasized the importance of mechanisms allowing for the evaluation of supervisors and the ability to appeal unfavorable evaluation results. Systems that support reciprocal evaluation, such as 360-degree feedback, contribute to fostering a culture of openness and promote the development of interpersonal competences across the organization (Fleenor, et al., 2020).

The Iterative Approach enables the dynamic adaptation of the assessment process to the changing needs of the organization and individual employees (Trzeciak, 2024). Pulakos et al. (2015) emphasize the importance of cyclical reviews and the updating of professional goals. In the context of this principle, it is worth referring to the PDCA cycle, which allows for systematic planning, implementation, monitoring, and improvement of processes. Survey respondents highlighted that the ability to regularly assess and update their goals contributes to increased motivation and engagement in professional development.

Constructive Feedback plays a key role in the employee evaluation process, supporting competency development and fostering employee engagement. As noted by Sedikides and Hepper (2009), feedback should be regular, specific, and improvement-oriented. Research by Murphy (2020) confirms that employees who receive constructive criticism combined with recognition of their achievements demonstrate greater commitment to fulfilling their responsibilities. Respondents in our study emphasized that positive and detailed feedback motivates them to take on new challenges and supports the development of a collaborative atmosphere within teams.

The respondents of the study emphasized the importance of the Open and Transparent Information Flow in the evaluation process. As noted by Stofkova and Sukalova (2020), open communication within an organization builds trust and supports developmental processes. Our research shows that clearly defined evaluation criteria are key to employee acceptance of the system.

A focus on the principle Targeted on Continuous Improvement plays a central role in effective employee evaluation processes. As noted by Minbaeva (2018), systems leveraging IT technologies enable ongoing performance monitoring and the identification of potential talent. Employees should be systematically supported in their development through access to training, mentoring, and feedback. Respondents in the study highlighted that regular evaluation reviews, combined with the establishment of clear career paths, enhance their engagement and job satisfaction. Implementing the principles targeted on continuous improvement allows organizations to adapt to changing market conditions and increases their competitiveness.

Ensuring a Stable and Balanced Development approach is essential for the long-term success of an organization. Venkat et al. (2023) highlight that a stable approach fosters engagement and reduces employee turnover. The research findings showed that respondents appreciate systems that consider their needs from both short-term and long-term perspectives.

5. Conclusion

The aim of this article was to develop principles that should characterize the employee evaluation process to make it effective, fair, and acceptable to employees. The research results, based on a literature review and surveys conducted among respondents, allowed for the identification of eight key principles, including: approach based on competences, practicality and simplicity, reciprocity and fairness of assessment, iterative approach, constructive feedback, open and transparent information flow, targeted on continuous improvement, and stable and balanced development.

The most significant findings indicate that effective employee evaluation requires not only technical tools but also a holistic approach that takes into account the needs and expectations of employees. It is crucial to create a supportive environment for professional development, based on transparent and fair evaluation criteria. Respondents particularly emphasized the importance of open and unrestricted communication, healthy relationships with colleagues and supervisors, and constructive, two-way feedback — from the employee to the supervisor and vice versa.

However, the conducted research has certain limitations. Firstly, the research sample consisted of 91 respondents, which is smaller than the commonly accepted sample size in social research. Nevertheless, the results provided a basis for developing preliminary principles for the employee evaluation process. Secondly, the analysis did not consider the impact of digital technologies on employee evaluation in various cultural and organizational contexts, which could be the subject of further research.

Future studies should expand the research sample to include diverse professional experiences as well as sectoral and cultural differences. Additionally, it will be important to examine the long-term effects of implementing the proposed principles and their impact on organizational efficiency and employee satisfaction.

References

1. Ahmed, I., Sultana, I., Paul, S.K., Azeem, A. (2013). Employee performance evaluation: A fuzzy approach. *International journal of productivity and performance management, 62(7)*, pp. 718-734.
2. Baird, K., Tung, A., Su, S. (2020). Employee empowerment, performance appraisal quality and performance. *Journal of Management Control, 31(4)*, pp. 451-474.
3. Bhave, D.P. (2014). The invisible eye? Electronic performance monitoring and employee job performance. *Personnel Psychology, 67(3)*, pp. 605-635.
4. Bracken, D.W., Rose, D.S. (2011). When does 360-degree feedback create behavior change? And how would we know it when it does? *Journal of Business and Psychology, 26(2)*, pp. 183-192.
5. Colquitt, J.A., Lepine, J.A., Wesson, M.J. (2015). *Organizational behavior: Improving performance and commitment. Organizational Behaviour.* McGraw-Hill Education. Retrieved from: www. mhhe.com.
6. Dangol, P. (2021). Role of performance appraisal system and its impact on employees motivation. *Quantitative Economics and Management Studies, 2(1)*, pp. 13-26.
7. Das, B.K., Rajini, G. (2023). Leadership development through 360-degree multi-rater feedback—An experience sharing of need, approach, roll-out, and the impact. *Environment and Social Psychology, 9(2)*.
8. DeNisi, A.S., Murphy, K.R. (2017). Performance appraisal and performance management: 100 years of progress? *Journal of Applied Psychology, 102(3)*, p. 421.
9. Fekete, M., Rozenberg, I. (2014). The practical model of employee performance evaluation. *Management, Knowledge & Learning*, pp. 141-149.
10. Fleenor, J.W., Taylor, S., Chappelow, C. (2020). *Leveraging the impact of 360-degree feedback*. Berrett-Koehler Publishers.
11. Gruman, J.A., Saks, A.M. (2011). Performance management and employee engagement. *Human resource management review, 21(2)*, pp. 123-136.
12. Gupta, N., Shaw, J.D. (2014). Employee compensation: The neglected area of HRM research. *Human resource management review, 24(1)*, pp. 1-4.
13. Jiang, H., Shen, H. (2023). Toward a relational theory of employee engagement: Understanding authenticity, transparency, and employee behaviors. *International Journal of Business Communication, 60(3)*, pp. 948-975.
14. Jończyk, J., Buchelt, B. (2015). Employee appraisal as the tool of the pro-innovative organizational culture formation in hospitals. *Journal of Intercultural Management, 7(2)*, pp. 135-150.
15. Kan, C.C., Tsai, W.C. (2003). *Applying Quantitative Proxies for Qualitative Evaluation Indicators: Employee Satisfaction and Customer Satisfaction*.

16. Kotamena, F., Senjaya, P., Putri, R.S., Andika, C.B. (2020). Competence or communication: From HR professionals to employee performance via employee satisfaction. *Jurnal Manajemen dan Kewirausahaan, 22(1)*, pp. 33-44.
17. Liebert, F., Trzeciak, M. (2016). Bariery realizowania projektów rozwoju nowych produktów w MŚP – część teoretyczna. *Zeszyty Naukowe, seria Organizacja i Zarządzanie, 96*, pp. 99-112.
18. Lin, Y.C., Kellough, J.E. (2019). Performance appraisal problems in the public sector: Examining supervisors' perceptions. *Public Personnel Management, 48(2)*, pp. 179-202.
19. Martin-Raugh, M., Tannenbaum, R.J., Tocci, C.M., Reese, C. (2016). Behaviorally anchored rating scales: An application for evaluating teaching practice. *Teaching and Teacher Education, 59*, pp. 414-419.
20. Meijerink, J.G., Beijer, S.E., Bos-Nehles, A.C. (2022). A meta-analysis of mediating mechanisms between employee reports of human resource management and employee performance: different pathways for descriptive and evaluative reports? In: *Strategic Human Resource Management and Organizational Effectiveness* (pp. 170-218). Routledge.
21. Minbaeva, D.B. (2018). Building credible human capital analytics for organizational competitive advantage. *Human Resource Management, 57(3)*, pp. 701-713.
22. Mulvaney, M.A. (2019). Examining the role of employee participation, supervisor trust, and appraisal reactions for a pay-for-performance appraisal system. *Public Organization Review, 19(2)*, pp. 201-225.
23. Murphy, K.R. (2020). Performance evaluation will not die, but it should. *Human Resource Management Journal, 30(1)*, pp. 13-31.
24. Naveed, R.T., Alhaidan, H., Al Halbusi, H., Al-Swidi, A.K. (2022). Do organizations really evolve? The critical link between organizational culture and organizational innovation toward organizational effectiveness: Pivotal role of organizational resistance. *Journal of Innovation & Knowledge, 7(2), 100178*.
25. Nudurupati, S.S., Garengo, P., Bititci, U.S. (2021). Impact of the changing business environment on performance measurement and management practices. *International Journal of Production Economics, 232, 107942*.
26. Panadero, E., Jonsson, A., Botella, J. (2017). Effects of self-assessment on self-regulated learning and self-efficacy: Four meta-analyses. *Educational research review, 22*, pp. 74-98.
27. Pichler, S., Beenen, G., Wood, S. (2020). Feedback frequency and appraisal reactions: a meta-analytic test of moderators. *The International Journal of Human Resource Management, 31(17)*, pp. 2238-2263.
28. Pulakos, E.D., Hanson, R.M., Arad, S., Moye, N. (2015). Performance management can be fixed: An on-the-job experiential learning approach for complex behavior change. *Industrial and Organizational Psychology, 8(1)*, pp. 51-76.

29. Rohmatunnisa, L.D. (2021). Leadership and Teamwork in Building Organizational Employee Performance. *International Journal of Educational Research & Social Sciences, 2(6)*, pp. 1406-1410.
30. Sedikides, C., Hepper, E.G. (2009). Self- improvement. *Social and Personality Psychology Compass, 3(6)*, pp. 899-917.
31. Shuck, B., Collins, J.C., Rocco, T.S., Diaz, R. (2016). Deconstructing the privilege and power of employee engagement: Issues of inequality for management and human resource development. *Human Resource Development Review, 15(2)*, pp. 208-229.
32. Stofkova, Z., Sukalova, V. (2020). Sustainable development of human resources in globalization period. *Sustainability, 12(18)*, p. 7681.
33. Szumiec, A., Trzeciak, M. (2024). Analiza wykorzystania i wpływu narzędzi Way of Working na skuteczność zespołów operacyjnych. *Studia i Prace Kolegium Zarządzania i Finansów, (198)*, pp. 117-130.
34. Thneibat, M.M., Sweis, R.J. (2023). The impact of performance-based rewards and developmental performance appraisal on innovation: the mediating role of innovative work behaviour. *International Journal of Productivity and Performance Management, 72(6)*, pp. 1646-1666.
35. Tomczak, D.L., Lanzo, L.A., Aguinis, H. (2018). Evidence-based recommendations for employee performance monitoring. *Business Horizons, 61(2)*, pp. 251-259.
36. Trzeciak, M. (2020). Key risk factors in it projects managed with the use of agile methods. *Scientific Papers of Silesian University of Technology, Organization and Management Series, No. 145*, pp. 533-546.
37. Trzeciak, M. (2024). Factors of success in the change management process of IT programs. *Journal of Organizational Change Management, 37(1)*, pp. 58-74.
38. Trzeciak, M., Banasik, P. (2022). Motivators influencing the efficiency and commitment of employees of agile teams. *Journal of Open Innovation: Technology, Market, and Complexity, 8(4)*, p. 176.
39. van Dam, K., Meulders, M. (2020). The adaptability scale. *European Journal of Psychological Assessment*, *37(2)*, pp. 123-134.
40. Venkat, M.V.V., Khan, S.R.K., Gorkhe, M.D., Reddy, M.K.S., Rao, S.P. (2023). Fostering Talent Stability: A Study on Evaluating the Influence of Competency Management on Employee Retention in the Automotive Industry. *Remittances Review, 8(4)*.
41. Wybrańczyk, K., Polok G., Naramski, M., Szormek, A.R. (2018). Przegląd procesu zmian w organizacji – przegląd wybranych koncepcji. *Zeszyty Naukowe Politechniki Śląskiej, seria Organizacja i Zarządzanie, Vol. 131*, pp. 623-634.

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THE PROBLEMS AND EFFICIENCY OF INVESTMENT IN SHARES OF COMPANIES WITH A LOW PRICE-TO-BOOK VELUE RATIO IN THE CONTEXT OF INTELLECTUAL CAPITAL ISSUE

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Purpose: The main aim of the article was to present the problems with application of the investment strategy based on companies with low P/BV ratio and to examine its efficiency taking also into account the enterprises' intellectual capital issue.
Design/methodology/approach: The study was conducted with respect to companies listed on the main market of the Warsaw Stock Exchange in the period 2009-2023 and was based on data published by WSE, which for individual companies included in particular P/BV ratio, P/E ratio, share price and EPS. The study was conducted in four approaches: (I) value companies identified only on the basis of P/BV ratio, (Ii) value companies with an additional result criterion, (III) value companies with an additional price criterion and (IV) value companies with an additional result and price criteria.
Findings: The study carried out in the field of analyzing the efficiency of investment strategies based on companies with low P/BV ratio values, including taking into account the issue of intellectual capital in the enterprise, allows to conclude that, at least from the point of view of the considered period of the study, this is an approach that allows "to overcome" market. At the same time, however, the results of the study showed that the use of easily accessible and popular additional criteria identifying companies in the portfolio does not necessarily provide an advantage over the broad market or the usual approach without additional criteria. This applies especially to a shorter time horizon.
Research limitations/implications: A certain limitation of the study and its results and final conclusions is the adopted, not very long, time frame (11 years), which was partly due to the availability of data and adaptation to the stock market cycle.
Practical implications: Investment strategies based on companies with low price-to-book value ratios are not on the losing end when compared to the market index.
Originality/value: The article presents an original approach to the application of the relationship between the market and book value of enterprises in terms of identifying value entities which have problems in the intellectual capital area. The article is addressed in particular to researchers dealing with the subject of valuation and measurement of intellectual capital in an enterprise, as well as analysts and stock market investors.
Keywords: P/BV ratio, intellectual capital, value stocks, investment strategy.
Category of the paper: Research paper.

1. Introduction

Investment strategies used by investors on the capital market can be very different (Jagielnicki, 2011; Damodaran, 2012; Zaremba, 2013; Jóźwicki, 2024). Some of the more popular and compared with each other in terms of results are the strategy of investing in shares of growth companies and the strategy of investing in shares of velue companies (Miller and Prondzinski, 2020). The first is most often associated with high values of price multiples, such as price to book value (P/BV) or price to earnings (P/E), and the second with their low values (Zarzecki, Wołoszyn, 2016; Penman, Reggiani, 2018; Miller, Prondzinski, 2020).

According to Chan and Lakonishok (2004), the discussion of growth and value stocks is one of the best examples of a successful exchange of ideas between academic research and investment practice. On the one hand, the results of academic research have formed the basis for investment strategies that have been implemented in the capital market. On the other hand, the investment community has developed procedures for identifying growth and value stocks and created benchmark indices for them, which has led to continued and deepened scientific research in this area.

The beginnings of dividing companies into the two groups indicated above, as well as the growing interest in the efficiency of investment strategies concerning them, are associated especially with the works of Fama and French (1992) as well as Lakonishok, Shieifer, and Vishny (1994), who drew attention to the so-called "value premium", i.e. higher rates of return on shares of value companies than on shares of growth companies. This premium is explained, on the one hand, by the higher risk of companies with low market multiples, associated with their financial problems and poor results (Fama, French, 1992), and on the other hand, by the underestimation by the market of shares of companies in a difficult financial and earnings situation (companies with value potential) and by the overestimation by the market of shares of growth companies characterized by improving financial and earnings situation (Billings, Morton, 2001; Skinner, Sloan, 2002; Haugen, 1995; Lakonishok et al., 1994; Penman, Reggiani, 2018; Dai, 2023).

The existence of the “value premium”, especially in the long term, is confirmed by numerous studies from various stock markets (Fama, French, 1992; Bauman et al., 1999; Sun, 2012; Gupta, Arora, 2019). This situation also undermines the efficient market hypothesis formulated by Fama (1970). According to it, stock prices reflect all information available at a given time, which means that investors cannot expect above-average profits (Malkiel, 2003).

It should also be noted that the advantage of value companies over growth companies in terms of the rate of return on investment is not sustainable over time. As long-term statistics for the US market show, periods of advantage of one group over the other are intertwined, with value companies more often on top and the average rate of return on investment in their case being higher (Giannotto, 2023; Hartford Funds, 2023; Dimensional, 2022).

At this point, it is also worth paying attention to the issues related to the intellectual capital of companies, which overlap with the above considerations, and in a simplified sense is identified with the difference between market value and book value, which is a direct reference to the price to book value ratio (Edvinsson, Malone, 1997; Sveiby, 2010). In this context, especially taking into account historically documented high rates of return, the issue of investing in shares of companies with values of this ratio below 1 is interestingly outlined, where, reasoning in accordance with the approach of Edvinsson and Malone, one can speak of a lack of intellectual capital, or even its negative value.

For this reason, the main aim of the article was to present the problems with application of the investment strategy based on companies with low P/BV ratio and to examine its efficiency taking also into account the enterprises' intellectual capital issue. The study was conducted with respect to companies listed on the Warsaw Stock Exchange based on their share quotations in the period 2009-2023.

The article consists of a theoretical introduction and its expansion in relation to the perception of the P/BV ratio, methodological part, research results and summary.

2. Price-to-book value ratio as a measure of the investment attractiveness of a company and its intellectual capital

2.1. Price-to-book value ratio in general

The market-to-book value ratio (MV/BV), or price-to-book value ratio (P/BV), is one of the most popular price multipliers used on the capital market as part of the financial analysis of companies (market indicators), their valuation (comparative methods), or the assessment of the investment attractiveness of their shares (Nawrocki, 2011):

$$\frac{MV}{BV} = \frac{Market\ Value}{Book\ Value} = \frac{P}{BV} = \frac{Share\ Price}{Book\ Value\ per\ Share} = \frac{Share\ Price}{\frac{Shareholders'\ Equity}{Number\ of\ Common\ Shares\ Outstanding}} \quad (1)$$

The market-to-book value multiple relates a company's market capitalization to the book value of its equity. This multiple is determined in particular by the expected dividend payout rate, expected growth rate, and risk. The most important factor influencing the multiple is the return on equity – higher rates of return result in higher P/BV multiples. The book value of equity is the difference between the book value of assets and the book value of total liabilities, which makes it very sensitive to the accounting principles applied. Since the book value of an asset reflects its original cost, it may differ significantly from its market value if the asset's value in use has significantly decreased or increased since the acquisition of control (Reilly, Brown, 2001; Janiszewski, 2011).

Depending on whether the equity in the company, which is the basis of the denominator of the P/BV ratio, is positive or negative, the P/BV ratio values can also take positive or negative values, whereby often in the case of negative equity in the company, the ratio is simply not counted and is marked with "x" or "–". The limit value of the ratio can be assumed to be 1, which means that the capital market values the company's shares at the same level as their book valuation (equity per share). Values of the ratio higher than 1 mean that the market valuation is higher than the book valuation, and values below 1 mean that the market valuation is lower than the book valuation (Czekaj and Dresler, 2005). At the same time, however, high values of the P/BV ratio (significantly above 1) do not necessarily mean that the shares of a given company are overvalued, and low values (significantly below 1) do not necessarily mean that they are undervalued.

The perception of overvaluation or undervaluation of a given company's shares by investors, apart from the P/BV ratio itself, is also determined by its financial condition and earning capacity, including in particular expectations regarding improvement in financial results (Sierpińska, Jachna, 2000; Borowski, 2014). A company's shares are overvalued when a high P/BV ratio corresponds to its poor financial condition and lower expectations for results. Companies in which high P/BV ratio values correspond to good financial condition and systematic improvement in financial results are usually positively assessed by the capital market, highly valued and referred to as growth companies. Such companies, apart from high price multipliers such as P/BV or P/E, are particularly distinguished by an upward trend in the results in the past, which according to forecasts is to be maintained in the future, high profitability of sales and return on equity (ROE) and no dividend payments (earned profits are invested in further development) (Segal, 2021). In turn, the undervaluation of a given company's shares can be said to occur when a low P/BV ratio corresponds to an improvement in its financial condition and an increase in result expectations. Companies in the case of which low P/BV ratio values correspond to poor financial condition and deterioration in financial results are usually negatively assessed by the capital market and valued low. Such companies are commonly called "value" due to a certain value potential that can be released if the problem blocking their development is removed (Mikołajewicz, 2014).

2.2. Low price-to-book value ratio as a determinant of low intellectual capital in companies

The interest in the P/BV ratio is not limited to the investment sphere, but has also appeared for many years in the discussion on the measurement of intellectual capital of enterprises in the management literature. The key issue in this context is the perception of intellectual capital (IC) in an enterprise as the difference between its market value (MV) and book value (BV) (Edvinsson and Malone, 1997; Sveiby, 2010):

$$IC = MV - BV \tag{2}$$

This approach to intellectual capital, due to the same variables, can be easily translated into the P/BV ratio (1).

Although the concept of intellectual capital has appeared in management literature for many years (Pirogova et al., 2020), it remains a category that is difficult to define unambiguously (Buenechea-Elberdin, 2017). Both in the literature and in business practice, there are different approaches to defining this category, and in research on the nature of intellectual capital, a certain terminological heterogeneity can be seen. Most often, this capital is identified with intangible assets, hidden assets, invisible assets, intangible assets, non-financial assets, intellectual resources, intangible resources, knowledge capital or intellectual matter (Bombiak, 2016; Śledzik, 2011). Generally speaking, it can be stated that in the definitions of intellectual capital it is perceived in two ways, i.e. as (Sydler et al., 2014; Bombiak, 2016; Hussinki et al., 2017):

- a factor that creates the value of an enterprise and strengthens its competitive advantage, or
- a sum of components, including in particular such as:
  - human capital – the intellectual potential of employees and the possibilities of using it determined by their motivation;
  - structural capital (internal, organizational) – organizational culture, systems, methods and processes, as well as organizational and information infrastructure facilitating the flow of knowledge within the organization and the use of human potential;
  - relational capital (external, network architecture) – all relationships with external stakeholders (investors, suppliers, customers), as well as the reputation resulting from these relationships.

The specificity of intellectual capital is well reflected in the “iceberg” model and the “tree” metaphor, which emphasize the importance of intangible values or resources, which are most often invisible to the environment, but at the same time have a greater ability to generate added value for the company than standard material resources visible in the balance sheet (Dobiegała-Korona, Herman, 2006; Adamska, 2015).

In relation to the above-mentioned concepts of intellectual capital, an interesting approach to its measurement, based on the difference between market value and book value (MV – BV) and particularly suitable for explaining the situation where MV < BV, was proposed by Sveiby (1989) in the form of the so-called "*the invisible balance sheet*". In this approach, the balance sheet containing intangible assets consists of two levels – the first is the visible part, which corresponds to tangible assets and book value, and the second is the invisible part, which describes intangible assets and their hidden sources of financing (Dziewulski and Skowron, 2020). In connection with the above, a higher value of BV over MV can be associated not so much with the total lack of intellectual capital, or its negative value, but with the company's problems in terms of certain assets in the invisible part, which obscure the positive effects of

other assets, giving generally weaker results "visible" in financial statements and negative perception by investors, which in turn leads to a devaluation of shares on the capital market.

Returning to the issue of using the P/BV ratio as a determinant of the level of intellectual capital in enterprises, it should be noted that this is a simple but at the same time very imperfect approach. Its criticism emphasizes its far-reaching generality (Kasiewicz et al., 2006) and combining the monetary value of intellectual capital with the value also generated by other types of capital in the enterprise (Jardon, Martinez-Cobas, 2021). In addition, attention is drawn to the significant burden of this approach, often occurring in the case of listed companies, with the significant dynamics of changes in their market quotations (prices), which may lead to distortions in the measurement and assessment of the level of intellectual capital of the analyzed entities (Nawrocki, 2022). In this respect, it is worth bearing in mind that the price of shares of companies on the stock market is influenced not only by objective factors, but to a large extent its changes are the result of investors' emotions and their reactions to various information and related expectations (Zaremba-Śmietański, 2013). This is especially true for the issue of the impact of external factors that are beyond the control of management staff and are characterized by randomness (Jarugowa, Fijałkowska, 2002; Palimąka, Mierzejewski, 2016). It should also be noted that regardless of distortions concerning market value, a similar problem may also occur with respect to book value, which is dependent on accounting principles (Bakuh et al., 2001). The criticism of measuring intellectual capital based on the difference between MV and BV also draws attention to the differences in the nature of these values. Book value is calculated based on historical balance sheet data, while market value is the result of predicting the situation of the company in the perspective of subsequent years (Palimąka, Gumieniak, 2014).

On the other hand, despite the wide criticism of the use of the P/BV ratio in measuring intellectual capital, its use is supported by its universality, which allows for external measurement of intellectual capital, the data necessary for measurement are publicly available, and the obtained results can be compared between companies, and it is also possible to present changes in the indicator over time (Bayer, 2014). Hence, this method is more suitable for the initial identification of entities with a potentially low level of intellectual capital, or even its absence, than for precise measurement in this regard. At the same time, its credibility can be increased by relying on the quotations, or P/BV ratio, of the analyzed companies in the form of an average or median over a longer period (preferably several years). Due to this, individual low readings, often the result of a temporary increase in emotions among investors, will only have a limited impact on the picture of the situation of the analyzed entities. Moreover, indications of a low level, or lack, of intellectual capital of the entities analyzed based on the P/BV ratio should be subject to verification based on an assessment of changes in their economic and financial situation (Nawrocki, 2022).

3. Research methodology

The main aim of the article was to present the problems with application of the investment strategy based on companies with low P/BV ratios and to examine its efficiency taking also into account the enterprises' intellectual capital issue. The study was conducted with respect to companies listed on the main market of the Warsaw Stock Exchange in the period 2009-2023, which was dictated by the availability of data, while verifying the following research hypotheses:

H1: Investing in companies with a low P/BV ratio allows you to beat the market, i.e. achieve a higher rate of return than the rate of return on the WIG index.

H2: Investing in value companies identified using an additional income criterion allows you to beat the market, i.e. achieve a higher rate of return than the rate of return on the WIG index.

H3: Investing in value companies identified using an additional price criterion allows you to beat the market, i.e. achieve a higher rate of return than the rate of return on the WIG index.

H4: Investing in value companies identified using both additional criteria, i.e. income and price, allows you to beat the market, i.e. achieve a higher rate of return than the rate of return on the WIG index.

H5: The use of an additional, resulting criterion identifying value companies increases the effectiveness of the investment compared to relying solely on the P/BV ratio.

H6: The use of an additional, price-based criterion identifying value companies increases the effectiveness of the investment compared to relying solely on the P/BV ratio.

H7: The efficiency of investing in value companies identified using additional criteria, i.e. income and price, is higher than the efficiency of investing in "ordinary" companies with value potential identified solely on the basis of the P/BV ratio.

H8: The efficiency of investing in companies with a low P/BV ratio increases with the length of the investment period.

H9: The effectiveness of investing in value companies identified using an additional income criterion increases with the extension of the investment period.

H10: The effectiveness of investing in value companies identified using an additional price criterion increases with the extension of the investment period.

H11: The effectiveness of investing in value companies identified using both additional criteria, i.e. income and price, increases with the extension of the investment period.

The study was based on data published by WSE (GPW, 2009-2023), which for individual companies included: number of shares issued, market value, book value, P/BV ratio and P/E ratio. All data is provided as of a given day. In addition, based on the above-mentioned data, the following were also calculated for individual companies: share price (market value / number of shares issued) and EPS (share price/P/E ratio).

Taking into account the main objective of the article, the formulated research hypotheses and the availability of data, the study was conducted in four approaches:

I. limited to the first decile of companies with the lowest P/BV ratio values on a given day (value companies identified solely on the basis of P/BV ratio);
II. limited to the first decile of companies with the lowest P/BV ratio values on a given day, while excluding companies without profit in a given year and 3 years back (value companies identified on the basis of P/BV ratio with an additional result criterion);
III. limited to the first decile of companies with the lowest P/BV ratio values on a given day, while excluding "penny" companies, i.e. those with a market price of one share below 1 PLN (value companies identified on the basis of P/BV ratio with an additional price criterion);
IV. limited to the first decile of companies with the lowest P/BV ratio values on a given day, while excluding companies without profit in a given year and 3 years back and "penny" companies, i.e. with a market price of one share below 1 PLN (value companies identified on the basis of P/BV ratio with additional criteria, i.e. result and price).

The calculations were to be carried out based on the adopted algorithm (Figure 1).

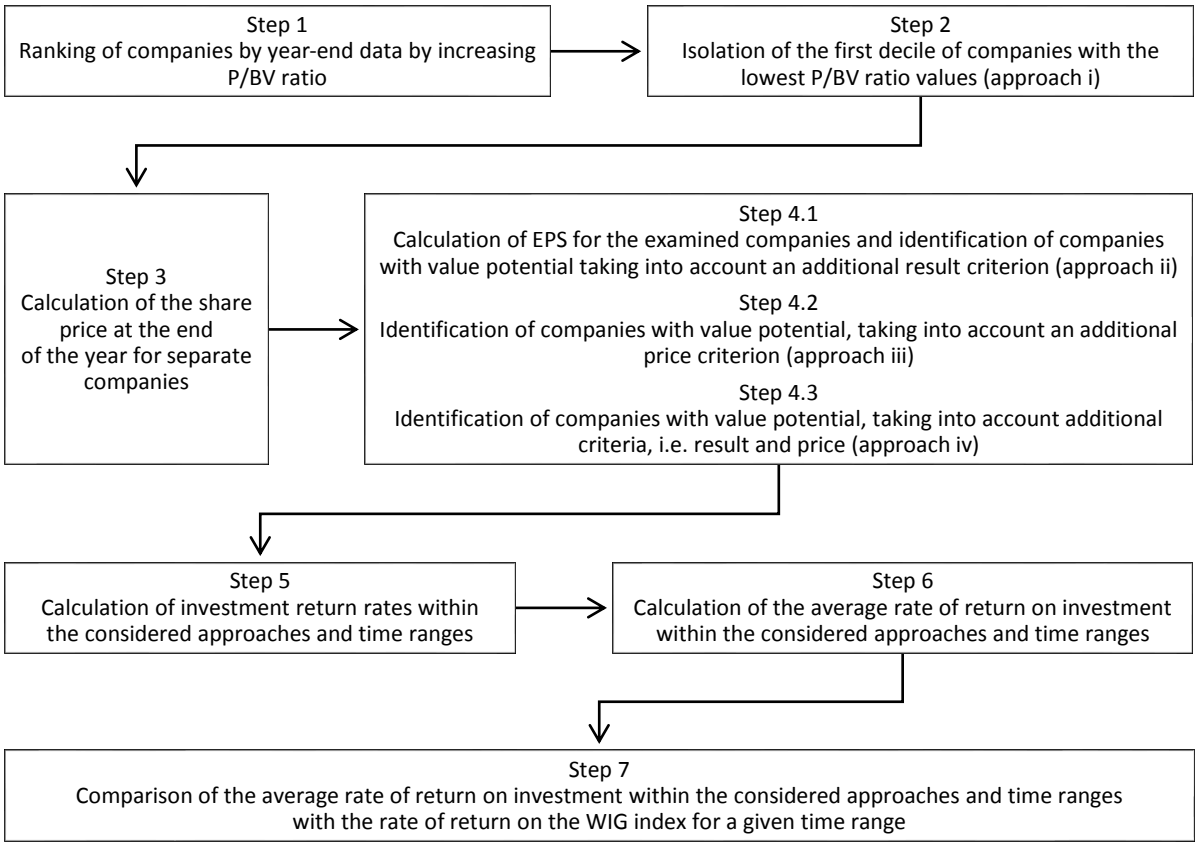

Figure 1. Calculation algorithm.

Source: Own work.

The arrangement of companies listed on the WSE main market according to year-end data by increasing P/BV ratio (step 1) was assumed to start from 2012 and end in 2022. Then (step 2), it was assumed to distinguish for each year the first decile of companies with the lowest P/BV ratio values (simple identification of value companies) and in step 3 to calculate the share prices at the end of the year for the previously distinguished companies in each of the years under consideration. In the broadly understood step 4, it was assumed to calculate an additional data, i.e. EPS, which will allow for the identification of value companies taking into account an additional result criterion, confirming a positive result situation, i.e. generating positive EPS (step 4.1), value companies taking into account an additional price criterion, i.e. share price above 1 PLN (step 4.2) and companies with value potential taking into account both of the additional criteria mentioned, i.e. income and price (step 4.3). In step 5, it was assumed that the investment growth rates were calculated within the considered approaches and time ranges (price from the examined period/price from the base period – 1), and then (step 6), based on them, the average rates of return were calculated (arithmetic mean). Taking into account also annual shifts within the time ranges of investments longer than one year, this gave for each of the considered approaches 11 one-year cases, 10 two-year cases, 9 three-year cases, 8 four-year cases, 7 five-year cases, 6 six-year cases, 5 seven-year cases, 4 eight-year cases, 3 nine-year cases, 2 ten-year cases and 1 eleven-year case. In the last, seventh step, it was assumed that the average rates of return calculated in step 6 within the individual approaches and time ranges would be compared with the rate of return from the WIG index for a given time range, which will allow us to determine whether a given approach allows us to beat the market.

4. Research results

The efficiency analysis of the investment strategy based on companies with low P/BV ratios, taking also into account additional criteria, was carried out in accordance with the methodology outlined in the previous section.

Due to the considerable volume of calculations and obtained results, the following sections limit the presentation only to the final results (rates of return on investment) within the individual approaches and time ranges (Tables 2-5), including, as a point of reference, the results for the WIG index (Table 6).

Table 2.
Individual and average rates of return on investment in value companies identified only on the basis of P/BV ratio – values for individual time ranges

Start year	Investment time frame in years										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
2012	21%	4%	1%	26%	58%	36%	38%	62%	65%	58%	62%
2013	-23%	-19%	-2%	-12%	-29%	-30%	-12%	3%	1%	2%	
2014	-5%	16%	30%	0%	-2%	37%	113%	117%	142%		
2015	22%	45%	-1%	-1%	39%	104%	107%	149%			
2016	5%	-29%	-25%	13%	37%	40%	76%				
2017	-31%	-39%	15%	63%	79%	89%					
2018	11%	81%	119%	113%	170%						
2019	143%	228%	150%	151%							
2020	52%	36%	100%								
2021	-5%	45%									
2022	48%										
Average	**22%**	**37%**	**43%**	**44%**	**50%**	**46%**	**65%**	**83%**	**69%**	**30%**	**62%**

Source: Own calculations based on WSE data.

Table 3.
Individual and average rates of return on investment in value companies identified based on P/BV ratio and the outcome criterion – values for individual time ranges

Start year	Investment time frame in years										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
2012	18%	2%	-4%	12%	32%	14%	16%	38%	42%	39%	43%
2013	-20%	-15%	-4%	-19%	-37%	-39%	-25%	-8%	1%	2%	
2014	-5%	8%	19%	-12%	-17%	20%	112%	118%	144%		
2015	16%	40%	-6%	-5%	26%	93%	103%	153%			
2016	2%	-28%	-25%	8%	37%	40%	85%				
2017	-29%	-38%	5%	53%	79%	104%					
2018	10%	84%	124%	117%	182%						
2019	108%	232%	159%	153%							
2020	50%	42%	115%								
2021	-8%	32%									
2022	45%										
Average	**17%**	**36%**	**43%**	**38%**	**43%**	**39%**	**58%**	**75%**	**62%**	**20%**	**43%**

Source: Own calculations based on WSE data.

Table 4.
Individual and average rates of return on investment in value companies identified with the P/BV ratio and price criterion – values for individual time ranges

Start year	Investment time frame in years										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
2012	17%	10%	17%	43%	85%	67%	57%	91%	97%	89%	95%
2013	-10%	-20%	-10%	2%	-28%	-23%	-11%	10%	32%	35%	
2014	2%	28%	47%	2%	-4%	47%	166%	184%	223%		
2015	27%	77%	22%	9%	58%	173%	207%	243%			
2016	12%	-31%	-29%	-10%	15%	22%	42%				
2017	-39%	-43%	-19%	24%	23%	81%					
2018	-7%	16%	63%	69%	93%						
2019	99%	159%	124%	105%							
2020	42%	40%	76%								
2021	-6%	43%									
2022	33%										
Average	**16%**	**28%**	**32%**	**30%**	**34%**	**61%**	**92%**	**132%**	**117%**	**62%**	**95%**

Source: Own calculations based on WSE data.

Table 5.
Individual and average rates of return on investment in value companies identified with the P/BV ratio and the result and price criteria – values for individual time ranges

Start year	Investment time frame in years										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
2012	6%	0%	6%	14%	53%	46%	32%	71%	78%	71%	78%
2013	-8%	-19%	-9%	1%	-27%	-24%	-14%	6%	32%	35%	
2014	4%	30%	50%	4%	-2%	46%	173%	190%	228%		
2015	29%	84%	26%	13%	55%	178%	210%	255%			
2016	7%	-30%	-29%	-9%	7%	13%	42%				
2017	-39%	-43%	-15%	21%	17%	94%					
2018	-7%	16%	63%	69%	93%						
2019	103%	166%	129%	109%							
2020	43%	41%	78%								
2021	-8%	29%									
2022	27%										
Average	**14%**	**27%**	**33%**	**28%**	**28%**	**59%**	**89%**	**130%**	**113%**	**53%**	**78%**

Source: Own calculations based on WSE data.

Table 6.
Individual and average rates of return on the WIG index

Start year	Investment time frame in years										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
2012	8%	8%	-8%	9%	34%	22%	23%	20%	46%	21%	65%
2013	0%	-15%	1%	24%	13%	14%	11%	35%	12%	53%	
2014	-15%	1%	24%	12%	14%	11%	35%	12%	53%		
2015	18%	46%	32%	34%	30%	58%	31%	79%			
2016	23%	11%	13%	10%	34%	11%	52%				
2017	-9%	-8%	-11%	9%	-10%	23%					
2018	2%	-1%	20%	0%	36%						
2019	-3%	18%	-2%	34%							
2020	22%	1%	38%								
2021	-17%	13%									
2022	37%										
Average	**6%**	**7%**	**12%**	**16%**	**22%**	**23%**	**30%**	**37%**	**37%**	**37%**	**65%**

Source: Own calculations based on WSE data.

In order to better illustrate the differences in the scope of the obtained research results, Figure 2 presents the average rates of return within the considered approaches and time ranges, taking into account the results for the WIG index as a reference point.

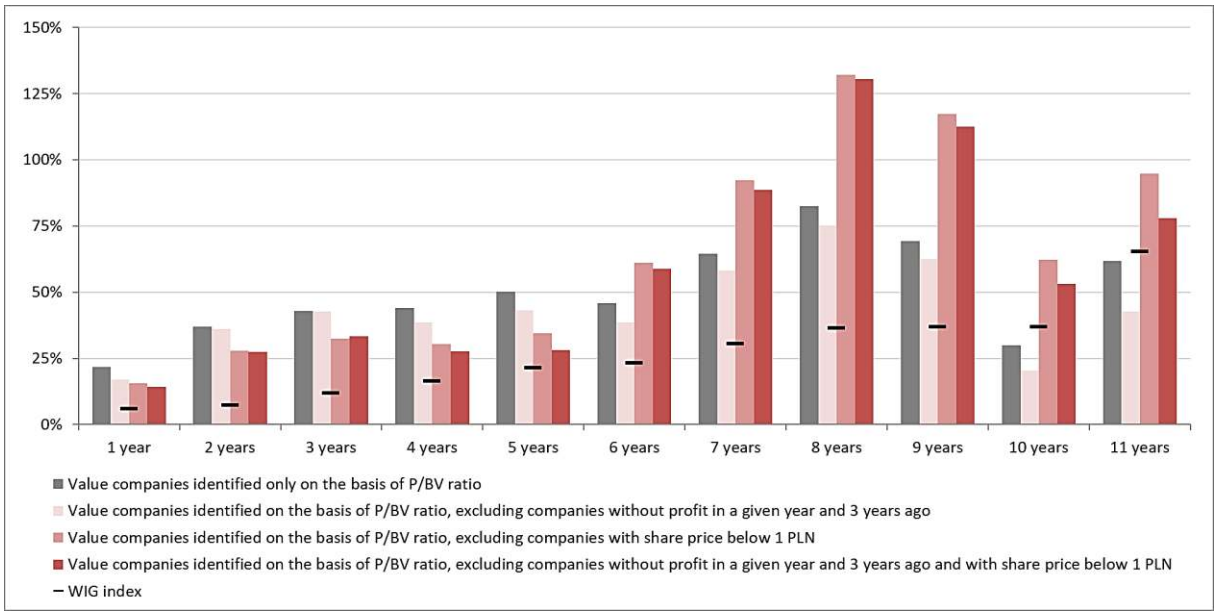

Figure 2. Average rates of return on investment for specific approaches and time ranges.
Source: Own calculations based on WSE data.

Taking into account the obtained results, it should be stated first of all that investments in companies with a low P/BV ratio from the perspective of average rates of return allowed to beat the market (WIG index) in almost all considered approaches and time ranges. Only in the long investment horizon (10 and 11 years) the average rate of return from the WIG index was higher than the average rate of return from value companies, but only those identified only on the basis of the P/BV ratio or with the additional exclusion of entities without profit in a given year and 3 years back. Therefore, from the point of view of average rates of return, hypotheses H1 and H2 can be considered partially true (for an investment horizon of up to 9 years inclusive), and H3 and H4 as fully true.

Secondly, the use of additional criteria (income and/or price) to identify value companies for investment has a positive impact on the average rate of return only in the longer term (from 6 years upwards) and mainly concerns the price criterion or the use of both additional criteria, i.e. income and price. Hence, assuming the perspective of average rates of return, it can be stated that hypothesis H5 is false, and hypotheses H6 and H7 are conditionally true, i.e. assuming an investment horizon of over 5 years.

Third, taking the perspective of average rates of return, the obtained results indicate that, in general, the efficiency of investments within the four approaches considered increases with the extension of the investment time range (hypotheses H8-H11), although at the same time this relationship is not perfect. In all approaches, there is a certain slight "retraction" of the rate of return for the investment period of 4 years and a much more pronounced one for investments lasting 9 and 10 years. Therefore, from the perspective of average rates of return on investment, hypotheses H8-H11 are only partially true, in particular with respect to shorter investment time ranges (up to 4 years).

At the same time, it should be noted that in detail, i.e. taking into account individual portfolios created in individual years for different time ranges, the obtained results do not allow for full confirmation of any of the formulated research hypotheses.

5. Summary

The conducted study on the analysis of the effectiveness of investment strategies based on companies with low P/BV ratio values allows us to state that, at least from the point of view of the period of the study under consideration, this is an approach that allows us to "beat" the market. At the same time, however, increasing the effectiveness of this investment approach and consolidating it over time requires the implementation of "more sophisticated" additional criteria in order to eliminate random and potentially problematic companies. As the results of the study have shown, the use of easily accessible and popular additional criteria identifying companies for the portfolio (EPS and price) does not necessarily provide an advantage over the broad market or the usual approach without additional criteria. This applies especially to a shorter time horizon. At the same time, however, it must be borne in mind that reaching for other, as they were called "more sophisticated", additional criteria is associated, due to their limited direct availability, with a much greater time and effort required to apply a given investment strategy.

It is also worth noting that even if the research hypotheses considered indicated the advantage of one approach over the other (strategies without additional criteria vs. strategies with additional criteria), this advantage was not complete, i.e. it did not apply to all the cases considered. In this respect, it should be borne in mind that changes in the prices of shares of companies on the capital market do not always result from their fundamental or technical situation. Moreover, on the capital market, similarly to the economy, we are dealing with the phenomenon of cyclicality, which means that even fundamentally weaker entities have better periods of quotations and their share prices increase. Hence, expecting a permanent victory over the market for a longer period of time is unlikely. These issues are discussed more broadly by the theory of market efficiency or the theory of random walk (Fama, 1970; Malkiel, 2014). Nevertheless, taking into account the results of the efficiency of the analyzed strategy, it can be stated that although it does not guarantee beating the market every time, it increases the probability of beating it in the longer term, provided that the established assumptions are adhered to.

Undoubtedly, a certain limitation of the conducted study and its results and final conclusions is the adopted, not very long, time frame (11 years), which resulted partly from the availability of data and adjustment to the stock market cycle.

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References

1. Adamska, M. (2015). Ewolucja koncepcji kapitału intelektualnego. *Przegląd Nauk Stosowanych*, *no. 9*, pp. 10-22.
2. Bauman, W.S, Conover, C.M., Miller, R.E. (1999). Investor overreaction in international stock markets. *The Journal of Portfolio Management*, *25(4),* pp. 102-111.
3. Beyer, K. (2014). Pomiar kapitału intelektualnego wskaźnikiem MV. *Studia i Prace Wydziału Nauk Ekonomicznych i Zarządzania Uniwersytetu Szczecińskiego*, *Vol. 38*, *no. 1*, pp. 9-19.
4. Billings, B., Morton R. (2001). Book to Market Components, Future Stock Returns, and Errors in Expected Future Earnings. *Journal of Accounting Research*, *Vol. 39*, *No. 2*, pp. 197-219.
5. Bombiak, E. (2016). Kapitał intelektualny jako specyficzny zasób współczesnych organizacji, *Zeszyty Naukowe Uniwersytetu Przyrodniczo-Humanistycznego w Siedlcach*. *Seria: Administracja i Zarządzanie, Uniwersytet Przyrodniczo-Humanistyczny (Siedlce), no. 36*, pp. 105-119.
6. Borowski, K. (2014). *Analiza fundamentalna*. *Metody wyceny przedsiębiorstwa*. Warszawa: Difin.
7. Buenechea-Elberdin, M., 2017, Structured literature review about intellectual capital and innovation. *Journal of Intellectual Capital*, *Vol. 18*, *No. 2*, pp. 262-285, doi: 10.1108/JIC-07-2016-0069.
8. Bukh, P.N., Larsen, H.T. Mouritsen, J. (2001). Constructing Intellectual Capital Statements. *Scandinavian Journal of Management*, *No. 17*, pp. 87-108.
9. Chan, L.K.C., Lakonishok, J. (2004). Vaule and Growth Investing: Review and Update. *Financial Analysts Journal*, *Vol. 60*, *No. 1*, pp. 71-86.
10. Czekaj, J. Dresler, Z. (2005). *Zarządzanie finansami przedsiębiorstwa.* Warszawa: PWN, p. 220.
11. Dai, K. (2023).The Value Premium Puzzle: A Comprehensive Review of the Empirical Evidence and Theoretical Explanations. *Advances in Economics*, *Management and Political Sciences*, *Vol. 32*, pp. 163-168.

12. Damodaran, A. (2012). *Investment philosophies*. *Successful strategies and the investors who made them work*. New Jersey: John Wiley & Sons, Inc.
13. Dimensional. (2022). *When It's Value vs. Growth, History Is on Value's Side*. Retrieved from: https://www.dimensional.com/us-en/insights/when-its-value-versus-growth-history-is-on-values-side, 20.09.2023.
14. Dobiegała-Korona, D., Herman, A. (2006). *Współczesne źródła wartości przedsiębiorstwa*. Warszawa: Difin.
15. Dziewulski, J., Skowron, S. (2020). *Struktura i pomiar kapitału intelektualnego*. Lublin: Wydawnictwo Politechniki Lubelskiej.
16. Edvinsson, L., Malone, M.S. (1997). *Intellectual Capital: Realizing Your Company's True Value by Finding Its Hidden Brainpower*. New York: Harper Business.
17. Fama, E.F, French, K.R. (1992). The Cross-Section of Expected Stock Returns. *Journal of Finance*, *Vol. 47*, *No. 2* (*June*), pp. 427-465.
18. 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.
19. Giannotto, R. (2023). *Trends in growth and value: Cycles and market regimes*. *A four-part analysis*. Retrieved from: https://content.ftserussell.com/sites/default/files/trends_in_growth_and_value_-_cycles_and_market_regimes.pdf, 20.09.2023.
20. GPW (2010-2022). *Indicators*. Retrieved from: https://www.gpw.pl/indicators.
21. Gupta, H.K., Arora, M. (2019). Factors influencing stock price of manufacturing sector: An empirical analysis of NSE listed companies. *Journal of The Gujarat Re-search Society, Vol. 21*, *No. 11*, pp. 346-356. Retrieved from: http://gujaratresearchsociety.in/index.php /JGRS/ article/view/896, 21.12.2023.
22. Hartford Funds (2023). *The Cyclical Nature of Growth vs. Value Investing*. Retrieved from: https://www.hartfordfunds.com/dam/en/docs/pub/whitepapers/CCWP105.pdf, 20.09.2023.
23. Haugen, R. (1995). *The New Finance: The Case against Efficient Markets.* Englewood Cliffs, New Jersey: Prentice Hall.
24. Hussinki, H., Ritala, P., Vanhala, M., Kianto, A. (2017). Intellectual capital, knowledge management practices and firm performance. *Journal of Intellectual Capital*, *Vol. 18*, *Iss. 4*, pp. 904-922, doi: 10.1108/JIC-11-2016-0116.
25. Jagielnicki, A. (2011). *Strategie inwestycyjne*. *Jak z głową zarabiać na giełdzie*. Gliwice: One Press.
26. Janiszewski, S. (2011). Zastosowanie wyceny metodą mnożnikową w transakcjach fuzji i przejęć. *Kwartalnik Nauk o Przedsiębiorstwie*, *Vol. 19*, *Iss. 2*, pp. 64-74.
27. Jarugowa, A., Fijałkowska, J. (2002). *Rachunkowość i zarządzanie kapitałem intelektualnym – koncepcja i praktyka*. Gdańsk: Ośrodek Doradztwa i Doskonalenia Kadr.
28. Jóźwicki, R. (2024). *Strategie inwestycyjne*. Warszawa: CeDeWu.
29. Kasiewicz, S., Rogowski, W., Kicińska, M. (2006). *Kapitał intelektualny*. *Spojrzenie z perspektywy interesariuszy*. Kraków: Oficyna Ekonomiczna.

30. Lakonishok, J., Shleifer, A., Vishny, R.W. (1994). Contrarian Investment, Extrapolation, and Risk. *Journal of Finance*, *Vol. 49*, *No. 5*, pp. 1541-1578.
31. Malkiel, B.G. (2003). The Efficient Market Hypothesis and Its Critics. *Journal of Economic Perspectives*, *Vol. 17*, *No. 1,* pp. 59-82.
32. Malkiel. B.G. (2014). *Błądząc po Wall Street*. Warszawa: Wolters Kluwer.
33. Mikołajewicz, G. (2014). Siła fundamentalna przedsiębiorstwa a strategie value investing i growth investing. *ZN Uniwersytetu Szczecińskiego*: *Finanse*, *Rynki Finansowe*, *Ubezpieczenia*, *no. 67*, pp. 327-337.
34. Miller, M., Prondzinski, D. (2020). Value Style Investing Versus Growth Style Investing: Evidence from the 2002-2019 Business Cycle. *Journal of Accounting and Finance*, *Vol. 20*, *No. 1*, pp. 131-151. doi: https://doi.org/10.33423/jaf.v20i1.2748.
35. Nawrocki, T. (2011). *Inwestowanie na rynku akcji*. *Jak ocenić potencjał rozwojowy spółek notowanych na GPW w Warszawie*. Warszawa: CeDeWu, p. 103.
36. Nawrocki, T. (2022). Issues of intellectual capital evaluation in an enterprise in relation to the method basing on the difference between its market and book value. *Zeszyty Naukowe Politechniki Śląskiej*. *Seria: Organizacja i Zarządzanie*, *nr 167*. Wydawnictwo Politechniki Śląskiej, pp. 365-381, doi:10.29119/1641-3466.2022.167.26.
37. Palimąka, K., Gumieniak, A. (2014). Wybrane metody pomiaru kapitału intelektualnego. In: E. Mieszajkina (Ed.), *Przedsiębiorczość i zarządzanie w gospodarce opartej na wiedzy*. Lublin: WSPiA.
38. Palimąka, K., Mierzejewski, M. (2016). Measurement of intellectual capital as exemolified by methods of groups based on ROA indicator and on market capitalization. *Financial Internet Quarterly* „*e-Finanse*”, *Vol. 12*, *No. 4*, p. 58-71, doi: 10.1515/fi qf-2016-0008.
39. Penman, S.H., Reggiani, F. (2018). Fundamentals of Value vs. Growth Investing and an Explanation for the Value Trap. *Financial Analyst Journal*, *Vol. 74*, *No. 4*, pp. 103-119, doi: http://dx.doi.org/10.2139/ssrn.2494412.
40. Pirogova, O., Voronova, O., Khnykina, T., Plotnikov, V. (2020). Intellectual Capital of a Trading Company: Comprehensive Analysis Based on Reporting. *Sustainability*, *Vol. 12*, pp. 7095, doi:10.3390/su12177095.
41. Reilly, F.K., Brown, K.C. (2001). *Analiza inwestycji i zarządzanie portfelem – cz. II.* Warszawa: PWE.
42. Segal, T. (2021). *Growth Investing: Overview of the Investing Strategy*. Retrieved from: https://www.investopedia.com/terms/g/growthinvesting.asp (28.12.2023)
43. Sierpińska, M. Jachna, T. (2000). *Ocena przedsiębiorstwa według standardów światowych*. Warszawa: PWN, pp. 114-115.
44. Skinner, D., Sloan, R. (2002). Earnings Surprises, Growth Expectations, and Stock Returns or Don't Let an Earnings Torpedo Sink your Portfolio. *Review of Accounting Studies*, *Vol. 7*, pp. 289-312. Retrieved from: https://doi.org/10.1023/A:1020294523516.

45. Sun, L. (2012). Information content of PE ratio, price-to-book ratio and firm size in predicting equity returns. *International Proceedings of Computer Science & Information Tech, Vol. 36*, pp. 275-281. Singapore: IACSIT Press. Retrieved from: http://www.ipcsit.com/vol36/050-ICIIM2012-M10011.pdf, 21.12.2023.
46. Sveiby, K.E. (1989). *The Invisible Balance Sheet*: *Key indicators for accounting, control and valuation of know-how companies.* Stockholm: Affarsvarlden/Ledarskap.
47. Sveiby, K.E. (2010). *Methods for Measuring Intangible Assets*. Retrieved from: https://www.sveiby.com/files/pdf/1537275071_methods-intangibleassets.pdf, 29.12.2023.
48. Sydler, R., Haefliger, S., Pruksa, R. (2014). Measuring intellectual capital with financial figures: Can we predict firm profitability? *European Management Journal*, *Vol. 32*, *Iss. 2*, pp. 244-259. Retrieved from: https://doi.org/10.1016/j.emj.2013.01.008.
49. Śledzik, K. (2011). *Kapitał intelektualny a wartość rynkowa banków giełdowych*. Gdańsk: Fundacja Rozwoju Uniwersytetu Gdańskiego.
50. Zaremba, A. (2013). *Giełda*. *Skuteczne strategie nie tylko dla początkujących*. Gliwice: Helion.
51. Zaremba-Śmietański, P. (2013). *Świadomy inwestor*. *Odkrywanie ukrytego potencjału spółki*. Gliwice: Helion.
52. Zarzecki, D. Wołoszyn, A. (2016). The Impact of Value and Growth Companies on IPO Underpricing on the Polish Capital Market. *Finanse*, *Rynki Finansowe*, *Ubezpieczenia*, *no. 4*, pp. 325-334, doi: 10.18276/frfu.2016.4.82/2-28.

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RESEARCH ON EMERGING NEW NARRATIVE IN PLACEBRANDING – WHERE SANCTUARY FACING FOOTBALL

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Purpose: Paper presents preliminary studies on city's placebranding in a face of a new storytelling factor. The text provides research on the phenomenon of new storytelling shaping the image of a place in the face of a placebranding already established in the consciousness of its inhabitants. The general aim of the research is to initial verification of an hypothesis of interactions between nationally recognizable success of a football club on Częstochowa city's perception change, which so far has a strongly dominant attribute as the world religious center.
Design/methodology/approach: The results of an empirical study were obtained to describe the potential for the transformation of a city's image from a story rooted in and related to its religious function to a new narrative. Survey interviews and in-depth interviews were used. Theoretical issues of place branding based on the sports story were addressed.
Findings: Identification of the existence of potential synergies between possible parallel place brand narratives. Preliminary evidence of differences in the perception of different groups of the city's community. It was observed in the face of the lack of cooperation and conflict towards the position of the football club in the city that there were no symptoms of the management of a new narrative by the city administration.
Research limitations/implications: A limitation of the study is the use of a relatively small non-representative research sample.
Practical implications: There may be practical implications in terms of recommendations for conflict management and place brand management for the city government scene.
Originality/value: This article is one of the few (or only) studies addressing the topic of rebranding a place from a religious function to a possible football narrative.
Keywords: Placebranding, narrative, city, football, religiosity.
Category of the paper: Research paper.

1. Introduction

We live in a world of competing narratives. An important dimension of this is competition not only between economic entities, but also between geographical areas and settlement structures. An important contemporary dimension of competition is the creation of suitable

images, connotations or attractive stories. We see this today in the form of business stories involving ecology, equality or social responsibility. Cities and regions also create and develop their own stories when competing for resources, including investment, residents, tourists. As Owsianowska notes, "nowadays, narratives are treated as one of the intangible values of a place - alongside image, identity, atmosphere, genius loci" (2014, p. 8). Stories create a brand of place (placebranding) which is an important dimension of territorial strategies. "Place branding is the management of place image through strategic innovation and coordinated economic, commercial, social, cultural and government policy" (Moilanen, Rainisto, 2009, p. 7). "Branding is everywhere and everything is a brand." (Richelieu, 2018, p. 354). Research on the phenomenon of placebranding has been developing rapidly since the late 1990s. At the same time, research on the importance of sport in placebranding and its impact on local communities and the perception of a city is quite abundant, especially in western scientific literature (Kobierecki, Strożek, 2017). Zenker (2014) and Richelieu (2014, 2018) distinguish between three objectives of placebranding: build brand awareness, improve the place's image in the mind of target consumers and stakeholders as well as to promote the location to different target markets. At the same time, for historical reasons, many cities and geographical places have an embedded brand and a set of associations, perceptions and stereotypes both within the community of inhabitants and among the external environment. As Marczewska notes "stereotypes are a component of the linguistic image of the world and the linguistic-cultural code, they are inevitable and indelible..." (2018, p. 283). Sometimes there are factors that change the direction of the narrative, moving away from stereotypes or building a new story.

The subject of the research presented in this paper is an attempt to answer the question about the possibility of a different perception of the city emerging in relation to the traditional socio-culturally rooted image and brand. The general aim of the research is to initial verification of an hypothesis of interactions between nationally recognizable success of a football club on Częstochowa city's perception change in the consciousness of its inhabitants, which so far has a strongly dominant attribute as the world religious center. Moreover, the aim of the studies is to analyze situations of conflict and cooperation occurring in this context.

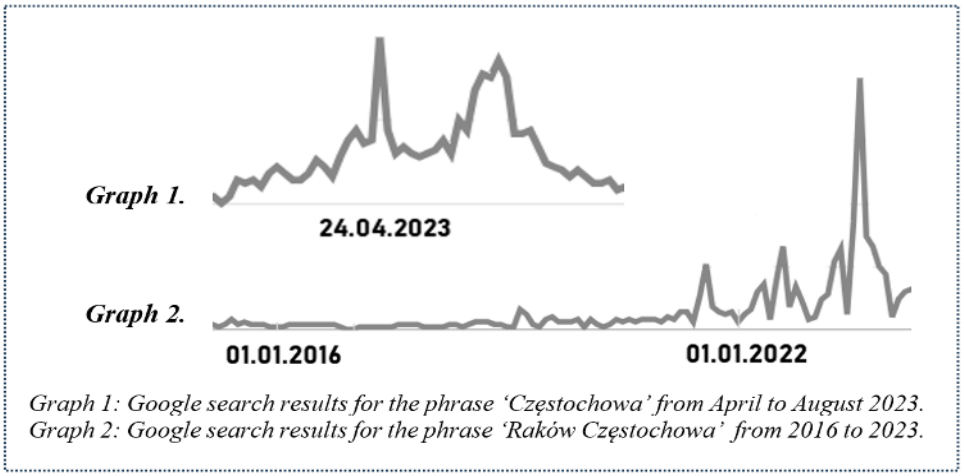
The ingrained image of the city Częstochowa is related to the perception of this place as a pilgrimage center. What interesting things have happened in the last years in the perception and image of the city? Perhaps a new factor of city perception has appeared. The city has become perceived in a new perspective because of the unexpected success of the local football club. While different contexts can feed into a place's branding strategy, such as history, architecture, gastronomy, sport can also be a significant lever for many image transformations. This is due to the emotional resonance of sport, its ability to engage the conversation with large audiences and high social emotion. Sport can become an important factor in the branding of a place (city) in the case of football such a process or activity is called 'a sport team platform' (Richelieu, 2018, p. 357). Hognestad mentions that in the world of club football, the tradition of a club, city or region is an important component in the symbolic construction of identity

(2009). As Melosik notes "in a world of dispersed values, football provides stable identifications" (2015, p. 323) Cities are increasingly striving to use a variety of sporting events and activities to create, change or re-fresh their image, promote it and, above all, for the purpose of activating the local economy (Bosiacki, Śniadek, 2012). It is observed that large cities support clubs that hold the greatest significance for the local community, and their successes, commented on by the media, simultaneously become strong promotion for the city. This case study of Częstochowa can lead to an identification of a process of place brand transformation or an emergence and manageability of new city-forming processes, as well as the conditions for effective management of conflict and cooperation, both in the business, image and social context. The research methodology will be based on survey questionnaires, in-depth interviews. Apart from the introduction, the study consists of a section describing the research context and the research methods used, based on a non-representative survey and in-depth interviews, a section on the presentation of the research results, discussion section and summary.

2. Research background and methods

Kotler et al. (1993) argues that the image of a place is a synthesis of beliefs, ideas, and impressions in the subjective relationship of people to that particular place, thus constituting a process of social perception. In this case Częstochowa, being a significant hub of global religious devotion, is epitomized by the Catholic Sanctuary of the Black Madonna. The sanctuary (Jasna Góra), serves as a complex religious and mythological construct, of utmost importance to Poland's history, symbolizing a key of national mythology. It also ranks among the world's foremost pilgrimage destinations, alongside places like Lourdes and Fatima. The comparative analysis underscores a notable trend, that European religious centers are typically found in small towns. These smaller urban areas, such as Fatima in Portugal and Lourdes in France have a population of just over 13,000 and are visited by 6 million and 5 million pilgrims/tourists respectively per year. While Częstochowa has a population of over 200,000 and receives over 4 million visitors (International la Croix, 2023). Minor European pilgrimage centers are primarily geared towards accommodating pilgrims, with their shrines serving as the primary—if not sole—urbanizing force. Conversely, the case of Częstochowa presents a starkly different scenario. Here, we encounter a multitude of simultaneous urbanization processes and various urban potentials. The city experiences a broader spectrum of city-genic activities, extending beyond accommodation and devotional trade to encompass a range of industrial and service sector investments. Nevertheless, the religious function remains the main connotation and brand of the city. Last years a new, a new narrative has emerged, the city has become popular in the media and public discourse because of the Raków Częstochowa football club. Figure 1 below shows the volume of searches in Google for the

phrase ‘Częstochowa’ from April to August 2023 and Google search results for the phrase ‘Raków Częstochowa’ from 2016 to 2023.



Graph 1: Google search results for the phrase ‘Częstochowa’ from April to August 2023.
Graph 2: Google search results for the phrase ‘Raków Częstochowa’ from 2016 to 2023.

Figure 1. Google search results for the phrase ‘Częstochowa’ and ‘Raków Częstochowa’.
Source: Author’s compilation based on Google Trends data (17.05.24).

It can be seen that the number of searches about the club was higher between the end of April 2023, when the club won the national championship, and the end of August 2023 (the peak of the pilgrimage period in the city), (Figure 1, Graph 1). At the same time, it can also be seen that there has been a spike in interest in the club in search results since the year of gaining promotion to the highest football league in the country (Figure 1, Graph 2). The history of football clubs in the city is not linked to successes and well-known stories so far. The origins of the football club, who changed the story can be traced back to 1921, where the Racovia Sports and Football Club was established in the workers' district of Raków on the initiative of the PPS and converted in 1924 into the Robotniczy Klub Sportowy (RKS) “Raków” (Gazeta…, 2021). With the exception of participation in the final of the Polish Cup in 1967, it did not achieve sporting success (Kowalski, 2015). The situation changed after the club was taken over by a local businessman from the IT trade industry. The story of x-kom began in 2002 when a 24-year-old graduate of the Częstochowa University of Technology opened the a small computer shop in the center of Częstochowa. As time passed, more shops emerged, but a pivotal moment for the company was its expansion into online sales. Today, enterprise stands as one of the largest stores in the Polish internet landscape, boasting revenues of 2.5 billion PLN (press.x-kom, 2024).

The empirical research used a methodology based on questionnaire surveys and their analysis, as well as qualitative research consisting of in-depth interviews. Survey research was conducted on a non-representative sample of Częstochowa city residents in the period November 2023 to February 2024. In the research, the respondents were divided into two groups. The first group consisted of people expressing an active interest in the sports club through regular attendance at football matches and participation in thematic groups on social media (group I, 78 people, responses received - 50). The second group consisted of people

expressing no active interest in the football club and never attending a match of the club football team (group II, 92 people, responses received - 50). The qualitative research was based on performing four in-depth interviews. Two interviews were conducted with club personnel, while the remaining two interviews were conducted with representatives of the city hall and Częstochowa city council. To complete the picture of the phenomenon under investigation, an analysis of selected media news during the period of May 2023 to April 2024.

3. Results

The survey was based on the questions (Q1, Q2, Q3, Q4, Q5) presented in the following table (Table 1), which concerned respondents' opinions on the possible process of changing the city's image due to the emergence of a new football story. In addition, the questions had to do with respondents' perceptions of a possible conflict between the city's existing brand as a religious center and the potential for building a capital of cooperation and trust within the city's community.

Table 1.
Questions in survey

Question 1 (Q1)	*Do you think that the sporting success of the club Raków Częstochowa contributes to changing the image of the city in the context of its religious function?*
Question 2 (Q2)	*Do you think such a change of image could have a positive impact on the city's development?*
Question 3 (Q3)	*Do you think the city's football narrative should be strengthened?*
Question 4 (Q4)	*Does the city's football narrative compete with or threaten the religious function of the city embedded in the inhabitants' consciousness?*
Question 5 (Q5)	*Do you think the increasing interest of local resident's in the football club has an impact on building an environment of cooperation and trust in the city?*

Source: author.

The aggregated results of the responses received, divided into two groups of respondents, that is those expressing an active interest in a sports club through regular attendance at football matches and participation in thematic groups on social media (*Active Fans*) and the second group were those expressing no active interest in a football club and never attending a match of a club football team (*Uninvolved Residents, observers*), are presented in the figure below (Figure 2).

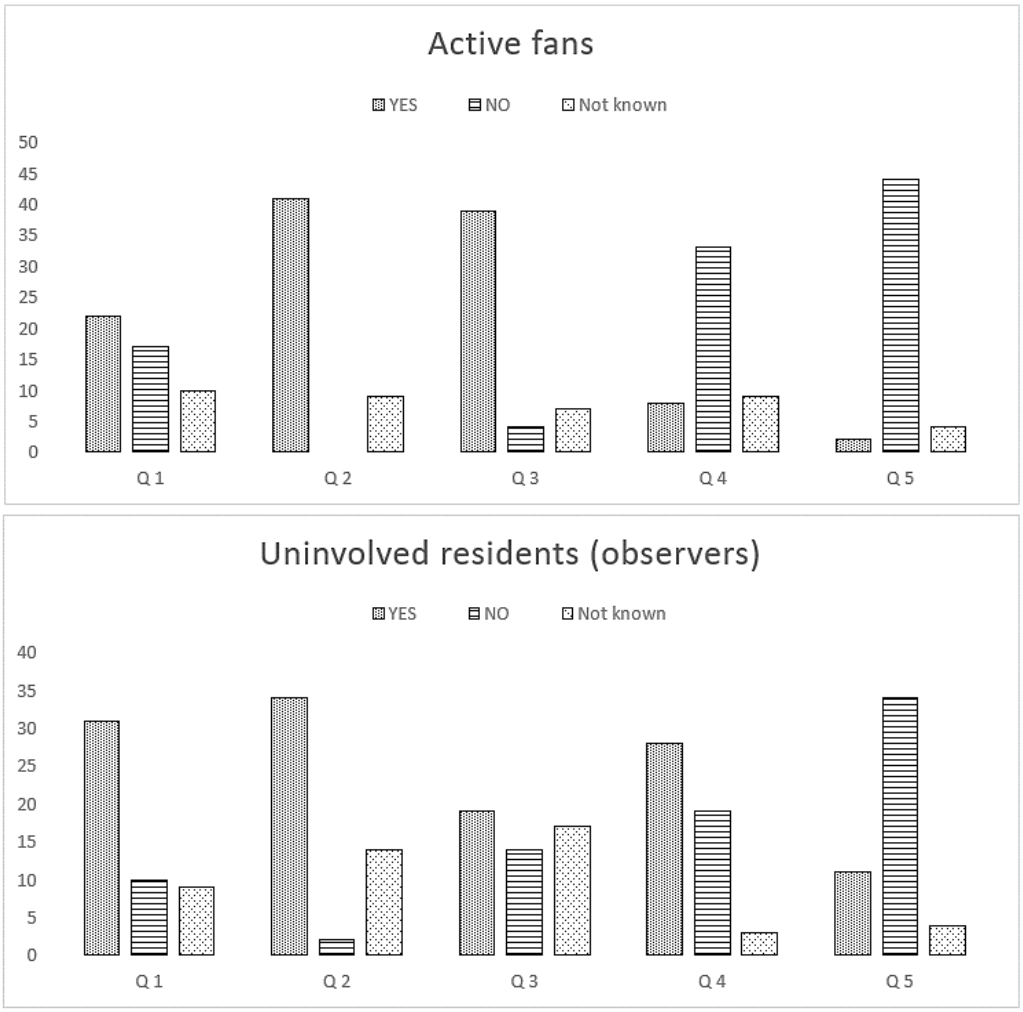


Figure 2. Results of the responses received, divided into two groups of respondents.
Source: author.

Differences can be noted in the perception of changing the image of the city in the context of its religious function (Q1), where more people who are not regular fans of the club indicate a possible change of image towards the religious function of the city in relation to active fans. Perhaps this is due to the prevalence of conservative attitudes in the football fan community. For question two (Q2) on the change of image could have a positive impact on the city's development, respondents of both groups express similar opinions. The answers to question three (Q3) on strengthening the city's sporting story indicate that more people in group one (active fans) consider strengthening the football story to be justified. This attitude is most likely due to a greater identification with the sporting narrative of this group.

There are clear differences in the answers to question four (Q 4) regarding the city's football narrative competing with or threatening the religious function of the city. Active fans indicate rather no such relationship, while uninvolved observers recognize that the football brand can compete with the religious brand. A possible explanation for this distribution of responses lies in the assumption of a greater attachment to conservative, right-wing and religious values among football fans. In the answers to the last fifth question (Q 5) concerning cooperation

capital and trust, we also notice differences between the two groups of respondents. Active fans express a more critical stance towards cooperation in the city environment compared to uninvolved observers of the football story. An explanation for this difference in the perception of cooperation capital could be the bitterness and high dissatisfaction with the situation of the football infrastructure for the club. Obviously, active fans attend matches so the lack of infrastructure is more noticeable for them.

In this section of the paper, the following is a summary of the qualitative research in the form of interviews and a review of media opinion. Interviews with football club activists (In 1, In 2) show that the position of the football club in relation to the local community is very well recognized and that the club creates a positive story that is well perceived. At the same time, respondents do not see any phenomenon of competition with the traditionally established brand of the place as a religious center, "maybe one day the pilgrims will also be interested in the club?" (In 1), "it might be interesting to have two stories" (In 2). At the same time, the club's activists see the club's role as fostering trust and social bonds, especially among children and young people. The biggest problem growing into a major barrier to growth and development is the lack of adequate technical infrastructure, especially the stadium and training facilities. The football community perceives this issue as a downright ideological problem or a personal conflict between the club and the city authorities It seems to be some kind of personal conflict, it cannot be rationally explained (In 2). Respondents highlight the lack of atmosphere and cooperation capital "I don't understand why there is this conflict after all it is obvious that it will work for the benefit of the city and the residents" (In 1). At the same time, they raise the political issue by recognizing that many activities related to the club on the part of the city and party circles always have a political context "there is no dialogue, "if there is it only during municipal elections like recently or parliamentary elections" (In 1).

Respondents representing the city (In 3, In 4) milieu point to the difficult cooperation with the club because of what they perceive as the club owner's desire to make a financial profit at the expense of the city budget "we have a huge problem with the lack of cooperation between the city and the club" (In 3). At the same time, they point out that there are possible solutions to the stadium problem "after all, there are public-private partnership solutions" (In 4). However, they claim that there is a very difficult and complicated financial set-up, which could affect the city's finances. On the part of the city authorities, there is no problem of a conflicting city brand, the respondents claim that there is a possibility of parallel narratives building the brand of the place "narratives can be complementary", "after all, it can coexist nicely" (In 4). Thus, from the interviews performed, it appears that the emergence of a new narrative about the city related to the popularity of the football club among inhabitants can be a complementary brand to the religious connotations of the city. At the same time, the biggest and so far unresolved problem is the conflict between the city authorities and the club. In this case, the strategic expectations are very different. The club expects explicit and significant help from the city in the development of sports infrastructure, while the city considers such contribution

as support for the business venture such as managing a football club. The main topic of media reports is the conflict over the construction of a new stadium for the football club or the possible redevelopment of the existing inadequate facility. It is apparent in media news stories that there is a lot of resentment and open conflict between the football supporters' community and the city authorities. “the current city mayor…, is not welcome at Raków matches. In the magistrate's office we hear that he doesn't go to the stadium if he has to listen to the whistles” (Polsat sport, 04.03.2024), “they challenged him during the championship fete and dedicated an offensive banner to him” (Sportowe fakty, 14.05.2023). At the same time, this subject is becoming a field of political game “one of the most important topics during the election campaign in Częstochowa was the construction of a new stadium” (Sportowe fakty, 22.04.2024). What emerges from the research is a picture of, on the one hand, a lack of perception of the development of the football story as any kind of threat to the established brand of the place, but on the other hand, a serious and deep conflict between the club and the political leadership of the city. It was observed in the face of the lack of cooperation and conflict towards the position of the football club in the city that there were no symptoms of the management of a new narrative by the city administration. It appears that the mixed research procedure applied allows conclusions to be drawn, but it should be stressed that the author is aware of the unrepresentative nature of the sample and treats these results as a preliminary stage in the study of these phenomena.

4. Discussion

The research procedure carried out, based on a non-representative research sample and in-depth interviews, obviously does not allow the results to be extrapolated to the population as a whole. Therefore, the conclusions presented in this article are based on subjective probability (Babbie, 2004; Chybalski, 2017). However, it seems that the results may be considered valuable as they represent a certain trend of the phenomenon related to the possibility of emergence or change of perception of the city image in the face of the appearance of a new factor. Bosiacki and Śniadek cite studies demonstrating the significant role of football in the perception of the city of Poznań, similarly Samura proves the significant role of the football club in the perception of the city. Daszkiewicz's research confirms the strength of associations of the football club as an image strength of the city of Poznań (2012). Among press publications about Poznań, sport-related topics predominate (39% of all publications), followed (more than twice as low) by information related to business (16%). (Rogala, 2011). As Samura noted (2012) Poznań is associated with "Lech", Warsaw with "Legia", Białystok with "Jagiellonia", Wrocław through "Śląsk", Kraków through "Wisła", and Łódź through "ŁKS" and "Widzew" (Samura, 2012, p. 159). Hognestad mentions that in the world of club football,

the tradition of a club, city or region is an important component in the symbolic construction of identity (2009). As Melosik notes ‘in a world of dispersed values, football provides stable identifications’ (2015, p. 323) Cities are increasingly trying to use a variety of sporting events and activities to create, change or ‘re-fresh’ their image, promote it and, above all, for the purpose of activating the local economy (Bosiacki, Śniadek, 2012). It is observed that large cities support clubs that hold the greatest significance for the local community, and their successes, commented on by the media, simultaneously become strong promotion for the city. Cities are increasingly striving to utilize various sports events and activities to create, change, or "refresh" their image, promote it, and above all, for the purpose of local economic activation (Bosiacki, Śniadek, 2012). Furthermore, it is recognized that the city's sports brand can influence the growth of social capital and collective identities (Kellett et al., 2008; Misener, Mason, 2009). Yet, the success of a local or the national team would fall under “collective identities” (Kavetsos, Szymanski, 2009), which refer to “the sense of belonging to a social group or community reflecting self-categorization with positive attitude and important self-concept in a social context” (Lee et al., 2013, p. 27). Either way, it seems that the empirical data and theoretical research presented are an interesting contribution to the scientific discussion on the possibility of transforming the image of place in the context of different narratives.

5. Summary

As Michalowski notes, “myth-making constructs play an important role in building the identity of cities” (2019, p. 28). Sports activities are an excellent way to shape myths and brand a place. An image is the way a territorial unit is perceived, the opinion about it, its image in the minds of the inhabitants. The activities of sports clubs can be a very effective form of promoting a city, especially when they achieve success on the national or international stage. Skillful use of good sporting results or clubs with positive associations for the promotional purposes of the territorial unit may increase interest in the city and, consequently, the number of tourists or companies willing to invest in the area. It seems that in the case of the studied problem of potential change or modification of the place brand of the city of Częstochowa, the biggest challenge is building culture of cooperation between local actors and trust capital. Referring to the main objective of the research, it can be said that a link was noted between the emerging new football story and the formation of the image of the place in relation to the long-established religious connotations of the city in the consciousness of its inhabitants. In addition, it was found that the presence of two narratives is not in competition with each other and can be complementary and reinforce the place brand. The research presented in this paper does not respond completely and convincingly the question of whether it is possible to transform the narrative about the city on the basis of a new factor constructing the image of the city.

However, it seems that posing such a question is an interesting contribution to the discussion on managing place identity and the image and perception of the city, although it is rather a preliminary identification of the problem. At the same time, it seems that the presented preliminary research results may be of significance in the construction of a city strategy in the context of placebranding management. Either way, it seems that further in-depth research in this subject is required in the future.

References

1. Anholt, S. (2007). *Competitive Identity*. Hampshire: Palgrave Macmillan.
2. Babbie, E. (2024). *Badania społeczne w praktyce.* Warszawa: PWN.
3. Bosiacki, S., Śniadek, J. (2012). Sport jako element strategii promocji miasta. *Przedsiębiorczość i Zarządzanie*, *Tom XIII, Z. 10*, pp. 13-23.
4. Chybalski, F. (2017). O uogólnianiu wyników analiz ilościowych w naukach o zarządzaniu. *Zeszyty Naukowe Politechniki Łódzkiej Organizacja i Zarządzanie*, *z. 67.*
5. Daszkiewicz, M. (2012). Badanie wizerunku miast z wykorzystaniem metod opartych na swobodzie skojarzeń. *Zeszyty Naukowe Uniwersytetu Szczecińskiego, nr 709, Problemy zarządzania, finansów i marketingu*, *nr 23*, pp. 257-266.
6. Gazeta Częstochowska. *Początki osady Raków i rakowskiego sportu*, *1513, Nr 10*, 11.03.2021.
7. Hognestad, H. (2009). Transglobal Scandinavian? Globalization and the Contestation of identities in football. *Soccer and Society, 10*, pp. 3-4.
8. *International la Croix*. Retrieved from: https://international.la-croix.com, 10.11.2023.
9. Kellett, P., Hede, A., Chalip, L. (2008). Social policy for sport events: leveraging (relationships with) teams from other nations for community benefit. *European Sport Management Quarterly*, *Vol. 8, No. 2*, pp. 101-121.
10. Kobierecki, M., Strożek, P. (2017). Sport as a Factor of Nation Branding: A Quantitative Approach. *The International Journal of the History of Sport*, *34(7-8)*, pp. 697-712.
11. Kotler, P., Haider, D.H., Rein, I., (1993). *Marketing Places – Attracting Investment, Industry and Tourism to Cities, States and Nations.* New York: The Free Press.
12. Kowalski, S. (2015). Profesjonalizacja marketingowego zarządzania w klubach sportowych na rynkach lokalnych. *Journal of Education, Health and Sport, 5(11)*, pp. 481-491.
13. Lee, S., Cornwell, T., Babiak, K. (2013). Developing an instrument to measure the social impact of sport: social capital, collective identities, health literacy, well-being and human capital. *Journal of Sport Management, Vol. 27, No. 1*, pp. 24-42.

14. Marczewska, M. (2018). Stereotypy etniczne we współczesnym polskim dyskursie publicznym. *Res Historica, 46*, pp. 283-300, orcid.org/0000-0002-2796-1317.
15. Melosik, Z. (2025). Społeczno-kulturowe konstrukcje piłki nożnej: męskość, kolektywna tożsamość i japonizacja. *Studia Edukacyjne, Nr 37*, pp. 313-326.
16. Michałowski, L. (2019). Trzy wymiary tożsamości miasta. *Miscellanea Anthropologica et Sociologica*, *20(4)*, pp. 25-37.
17. Misener, L. Mason, D.S. (2009). Fostering community development through sporting events strategies: an examination of urban regime perceptions. *Journal of Sport Management*, *Vol. 23 No. 6*, pp. 770-794.
18. Moilanen, T., Rainisto, S., (2009). *How to Brand Nations, Cities and Destanations*. Hampshire: Palgrave Macmillan.
19. Niedźwiedź, A. (2000). *Obraz Matki Boskiej Częstochowskiej w kręgu mitologii narodowej*. *Religia i polityka*. Kraków: Wydawnictwo Uniwersytetu Jagiellońskiego, pp. 75-85.
20. Owsianowska, A. (2014). Stereotypy w narracji turystycznej. *Turystyka Kulturowa, No. 3,* pp. 6-20.
21. *Polsat Sport*. Retrieved from: https://www.polsatsport.pl/wiadomosc/2024-03-04/mowi-o-kompromitacji-wladz-i-pragnie-zmian-dla-rakowa-oni-nie-chca-wybudowac-tego-stadionu. 11.05.2024.
22. *Press x-kom*. Retrieved from: https://press.x-kom.pl/138463-stworzyl-swietnie-prosperujacy-x-kom-przeniosl-sie-do-sportu-i-tez-wyszlo, 4.03.2024.
23. Rein, I., Shields, B. (2007). Place branding sport: Strategies for differentiating emerging, transitional, negatively viewed and newly industrialised nations. In: *Place Branding and Public Diplomacy, III* (pp. 73-85). Hampshire: Palgrave Macmillan.
24. Richelieu, A. (2014). The strategic management of the brand in the world of sport. *Journal of Brand Strategy*, *Vol. 2, No. 4*, pp. 403-415.
25. Richelieu, A. (2018). A sport-oriented place branding strategy for cities, regions and countries. *Sport, Business and Management: An International Journal, Vol. 8, No. 4*, pp. 354-374.
26. Rogala, A. (2011). Rola sportu w promocji miast. *Zeszyty Naukowe Uniwersytetu Szczecińskiego. Ekonomiczne Problemy Usług*, *nr 79*, pp. 217-227.
27. Samura, M. (2012). Rola sportu w promocji miast. *Refleksje, wydanie specjalne*, pp. 153-167.
28. *Sportowe Fakty WP*. Retrieved from: https://sportowefakty.wp.pl/pilka-nozna/1060227/kibice-rakowa-zaatakowali-prezydenta-czestochowy-na-oczach-calej-polski, 10.04.2024.
29. *Sportowe Fakty WP*. Retrieved from: https://sportowefakty.wp.pl/pilka-nozna/1118499/obiecal-stadion-i-wygral-wybory-fani-rakowa-pokazali-co-o-nim-sadza, 30.03.2024.

30. Zenker, S. (2014). Measuring place brand equity with the advanced Brand Concept Map (aBCM) method. *Place Branding and Public Diplomacy*, *Vol. 10, No. 2*, pp. 158-166.
31. Zenker, S., Beckmann, S.C. (2013). My place is not your place – different place brand knowledge by different target groups. *Journal of Place Management and Development*, *Vol. 6, No. 1*, pp. 6-17.

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SOCIAL POTENTIAL OF MODERN ORGANIZATIONS IN POLAND – A FUNDAMENTAL CHALLENGE

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Purpose: The article attempts to identify the socio-cultural and economic causes of the phenomenon of organisational withdrawal in Poland in a historical perspective.
Design/methodology/approach: The analysis is based on found empirical research put in perspective.
Findings: The phenomenon of organisational disengagement seems to be the result of a lack of resolve in choosing the logic of organisational life (Anglo-Saxon and Scandinavian/Alpine logics). The above situation generates a disorganisation of organisational identity - the attitude towards the company.
Research limitations/implications: Co-creating the external environment of the organization significantly affects the real shape of employee attitudes. Every organization creates an informal structure, because very often its participants face unforeseen situations for which there are no procedures defining how to proceed. What's more - people want to control their environment, not just be subjected to control. Informal ties are a natural consequence of the desire for subjectivity in an organization.
Practical implications: In Polish conditions, the theoreticians and practitioners of management science should focus their attention on the real - transferred from the organisation's environment – foundations of organisational culture.
Social implications: The analysis presented shows the importance of the social dimension of an organisation's functioning and the impact of the external environment on its functioning.
Originality/value: The author highlights the importance of changing attitudes towards the workplace and identifies their causes.
Keywords: organization, the logic of organisational life, anomie, organisational withdrawal.
Category of the paper: Research paper, Viewpoint.

1. Introduction

When analyzing organizational behavior – including cotrproductive behavior – in the conditions of Polish economic reality, it is necessary, in my opinion, to take into account the process of social, cultural and economic change initiated in the 1990s. This process, which is in fact a continuous change and a kind of social experiment, continues to this day.

I assume that in the sociological, economic, management and quality sciences perspective it is a state of social anomie generating counterproductive behavior. Co-creating the external environment of the organization significantly affects the real shape of employee attitudes. The observed social experiment had its origins in the indecision about the shape of the dominant logic of management in Poland. It is a choice between the Anglo-Saxon or Scandinavian-Alpine perspective of economic activity and the social definition of the enterprise as a workplace, as illustrated in the following tables:

Table 1.
Dominant investment resources vs. management logic

Scandinavian-Alpine logic (investment resources)	Anglo-American logic (investment resources)
Banking system	Exchange system

Source: Own compilation based on (Szomburg 1993, p. 7-8).

Table 2.
Enterprise characteristics vs. management logic

Scandinavian-Alpine logic (investment resources)	Anglo-American logic (investment resources)
An enterprise is a place where many needs (e.g., security, belonging, work ethos) are fulfilled.	Enterprise is treated in terms of a "commodity". It is the place where meritocratic needs are realized.
Companies merge or buy each other's shares to spread risks or financial burdens (social market economy).	Violent corporate takeovers or spin-offs. The possibility of rapid changes in significant blockholders.
Managers devote themselves entirely to management.	Managers are forced to watch changes in the capital markets.

Source: Own compilation based on (Szomburg, 1993, pp. 7-8).

The paradigm of economism (economics dissected from its social and cultural context) adopted at the time led to a situation in which economics, striving for a scientific ideal, limited itself to analyzing how people use money. The question for what purpose they do it and what motivations drive them in scientific discourse has been marginalized. Similarly, in the sciences that address the issue of managing the social potential of organizations. In this case, it is, to say the least, incomprehensible if we consider the research conducted at the Hawthorne Plant owned by the Western Electric corporation in 1924-1932, which was supervised by Elton Mayo, among others. At that time, it was found that there was a strong influence of group norms on the individual behavior of employees, which gave rise to the "human relations" school (Szmatka, 1989):

- Groups with an informal structure are formed in the various departments.
- These groups, through a system of norms developed by their participants, exert strong pressure on them.

Defined standards:

- You should not produce too much. If you do, you are a "norm breaker" – a rate-buster.
- You should not produce too little. If you do, you will be called a "blinker" – a chiseler.

- You should not say anything to your superior that may harm a colleague. If you do this, you are a "traitor" – a squeler.
- Do not demonstrate your position in the hierarchy. If you are a superior, do not act defiantly (shorten the distance).

Every organization creates an informal structure, because very often its participants face unforeseen situations for which there are no procedures defining how to proceed. What's more – people want to control their environment, not just be subjected to control. Informal ties are a natural consequence of the desire for subjectivity in an organization. I assume that a sense of subjectivity combines a sense of control over reality and a sense of integration with reality, while causality is a conscious activity oriented toward achieving a specific goal (Beskid et al., 1995). According to Zbigniew Zaborowski, subjectivity manifested by exercising power and maintaining control can be divided into three levels (Zaborowski, 1991):

1. Informational subjectivity – one's own (subjective) way of receiving and interpreting information about oneself and the surrounding world.
2. Pragmatic subjectivity – spontaneous search for effective ways to act and their practical implementation.
3. Axiological subjectivity – activity resulting from certain values and views according to which a person acts.

The field of economics is defined by a paradigm of efficiency and productivity achieved through defined organizational roles, the principle of competence and hierarchy. Today's broadly defined culture emphasizes a holistic view of social actors with particular emphasis on the need for self-realization. However, organization is a process of logic of integration and conflict at the same time. The notion of organizational structure, itself assuming order and rationality, distorts the actual arrangement of forces and dependencies. The logic of industrial society is at odds with the cultural demand for self-realization. The dilemma of choosing between the requirement for formalization and the progressive individualization of the needs of the organization's external environment also concerns the issue of the subjective treatment of subordinates. From the point of view of the organization's social potential, it is a matter of harmonizing the possibility of demonstrating competence in the shortest possible time with the use of facade elements: decoration, the scenic part of the means of expression, as a factor of social stability, and the personal facade - those means of expression that are related to the performer of the role himself (Goffman, 1981). Organizational roles effectively project definitions of situations while influencing the way a given state of affairs is understood by making it possible to organize and coordinate actions, as well as to give up claims to be someone else (Goffman 1981). Expansive career paths, or strictly normatively defined patterns of action, serve this purpose). The identification methods used in this case are part of a psychological contract containing a set of unwritten expectations of the employee on the one hand, and on the other hand of the organization specifying three types of issues (Strategor, 1999):

1. Mutual claims based on the idea of interdependence (work, facilitating relationships with others, support, protection, psychological stability, information, education - loyalty and commitment).
2. Mutual learning (creating opportunities for development).
3. Mutual control.

According to Michel Crozier and Erhard Friedberg organizational behavior often deviates from formally defined organizational roles (Crozier, Friedberg, 1994). In other words:

1. The organizational situation does not completely limit the freedom of organizational participants. Having a certain margin of freedom, they have the opportunity to negotiate.
2. The participants of the organization have a certain amount of power, so their behavior should be considered, as the result of a rational strategy leading to the best use of their power to negotiate the most profitable terms of participation.
3. Action strategies contain two opposing but complementary dimensions: the offensive dimension – the constant effort to reduce the action of the freedom of others; the defensive dimension – to avoid reducing one's own freedom.

2. The social context of counterproductive behavior in the organization

In the context of analyzing counterproductive organizational behavior, it is necessary, as indicated above, to take into account the role and importance of attitudes and behaviors "brought" by employees from the so-called external environment of the organization into its system of functioning. This is related to the issue of the organization's culture. It can be understood as (Konecki, Tobera, 2002):

- independent variable – an external factor that directly influences and determines labor and managerial behavior in a country;
- dependent variable – an element of the organization that depends on the existence of other organizational elements (e.g., property rights, transaction costs and the activity of the entrepreneur or organizational leaders oriented towards creating positive attitudes to work or building an organizational strategy in which, for example, the company's mission is defined influencing the values and norms recognized throughout the organization);
- as an autonomous entity – not determined by the culture found in the environment of the country and other factors of the internal environment of the organization independent of it (a form of expression and manifestation of human consciousness – the organization is "culture").

Taking into account the cultural paradigm, I assume that the culture of an organization is derived from the independent variable and the dependent variable. They are autonomous but complementary. I consider the characteristics of the external environment and the type of organization to be the primary determinants of organizational culture. I treat the features of organizational culture as derivatives of the values that co-create the organization's environment. Thus, its participants correspond more to the model of "sociological man" (homo sociologicus), rather than "economic man" (homo oeconomicus). This "socially rooted" man in his actions is based on values rather than interests.

The concept of social anomie, which co-creates the context of counterproductive behavior in organizations, has its intellectual origins in the analysis of the destruction of the axionormative order at the end of the 19th century - a discussion of the social, political and economic consequences of the above phenomenon. The phenomenon of anomie is now considered in terms of objective states of society and subjective states of individual consciousness. For Emil Durkheim, anomie is a state "(...) in which the normative system loses coherence and turns into chaos. Signposts of action - goals and means - become vague, ambiguous. People lose their sense of what is good and what is bad, what is worthy and what is unworthy, what should be pursued and what should be avoided, what methods are allowed and what are forbidden. Disorganization of normative culture means disorientation of members of the collective"(Sztompka, 2002, p. 275). Robert K. Merton redefined the concept of anomie by linking it to an emphasis on two elements of social and cultural structure (Merton, 1982):

- culturally defined intentions or interests taking the form of sanctioned goals for "all or variously positioned members of society",
- customarily or legally sanctioned ways of achieving these goals.

According to Merton, cultural goals and the institutionalized norms that shape the spectrum of dominant behavior need not be closely related because the cultural pressure for certain goals can change. In other words - the desire to achieve a culturally sanctioned goal can become independent of the institutionalized methods of aiming at it. Possible strategies of action are: conformism: acceptance of goals and institutionalized means; innovation: acceptance of goals while rejecting means to reach them; ritualism: rejection of goals and acceptance of means; disengagement: negation of goals and means; rebellion: rejection of goals and means and proposal of their alternatives. In a situation of radical reconstruction of the socio-economic order, the existing system of values is eroded, therefore the phenomenon of employee anomie – intentional and systematic behavior that causes widely defined losses for the organization – is growing. These are (Kowalewski, Moczydlowska, 2020):

- theft and destruction of the organization's property,
- falsification of documentation,
- cheating and using violence against co-workers,
- aggressive and potentially dangerous behavior,

- nepotism,
- misappropriation of the achievements of other employees,
- disclosure of organizational secrets,
- pretending to work,
- leaving the workplace without permission from superiors,
- taking care of private matters while working,
- prolonging breaks, arriving late and leaving work early,
- drinking alcohol and using psychoactive substances,
- simulating illness.

At this point, it is worth noting that the concept of labor anomie in relation to counterproductive behavior is beginning to lose semantic precision. We distinguish five types of counterproductive behavior (Turek, 2012):

- abuses against co-workers,
- theft,
- production deviation,
- organizational sabotage,
- withdrawal.

Attempts to identify differences between anomie and counterproductive behavior are, in my opinion, devoid of substantive justification. Already the state of anomie (a person in a situation of temptation and/or humiliation), whether in the sense of Emil Durkheim or Robert K. Merton, generates the need to build a peculiar system of rationalization of actions taken. Due to the multiplicity of theoretical conceptualizations of pathology and dysfunction in organizations present in the literature, I will skip the related scientific discourse. This would exceed the capacity of the volume of this analysis, so I will focus my attention on the phenomenon of organizational withdrawal similar to the so-called quiet quitting (lack of emotional involvement in work). It is similar to one of Robert K. Merton's proposed survival strategies – the negation of ends and means.

3. Organizational withdrawal – diagnosis

Behaviors inherent in organizational withdrawal are (Filas, https://zawodowysos.pl/zachowania-kontrproduktywne-w-organizacji/):

1. Intentional tardiness.
2. Reducing work time.
3. Extending breaks.
4. Leaving the workstation.

5. Intentionally performing work more slowly.
6. Taking undue days off.
7. Simulating illness.
8. Surfing the Internet during working hours.

I assume that counterproductive behaviors can be legal (e.g., taking care of personal matters during work time) and illegal (e.g., drinking alcohol in the workplace) (Bowling, Gruys, 2010). Their differentiation is also determined by the nature of their association with work (e.g., slower performance of job duties or use of violence against co-workers).

The distinction indicated has serious implications in the area of organizational behavior. This is because the inherent legitimacy of withdrawal makes it possible to survive in an organization, and taken as an inferential indicator, it exposes the weakness of the incentive systems used and forces us to ask the basic question: how do we perceive our workplace? This seems to be one of the consequences of the indecision cited at the beginning of the analysis regarding the choice of the dominant logic of management and its corresponding "organizational architecture". Conducted in September 2022 by ARC Rynek i Opinia on behalf of Pracuj.pl, the study "Work in times of change" (https://media.pracuj.pl/215457-zaangazowani-ale-nie-zmotywowani-polacy-w-pracy) addressed, among other things, the phenomenon of quiet quitting. The survey "Work in times of change" was conducted in September 2022 by ARC Rynek i Opinia on behalf of Pracuj.pl. Measured using the CAWI method, it was conducted on a sample of 2110 Poles, representative of the working population aged 18-65 in terms of gender, age and size of place of residence. Changes in attitudes toward work, according to which an employee gives up ambitions beyond his or her basic duties – disagreement with engaging in new tasks, working overtime and lowering ambitions for career advancement. Involvement in current duties was declared by 79% of respondents. Only 39% of working respondents were convinced that in their work, the extra commitment pays off for the employee. 54% of Poles spend an average of 8 hours a day at work. 8 out of 10 respondents are engaged in their work tasks. 37% of respondents said they focus only on formal duties. Poles perceive themselves as reliable professionals, although for some this is not matched by a readiness to carry out additional tasks - to go beyond the rigid framework of the daily schedule. Only 4 out of 10 respondents were of the opinion that in their place of employment an above-normal commitment to work pays off for the employee. A large percentage of those exemplifying work responsibilities were not fully convinced of the real impact of such an attitude on an employee's salary. Reluctance to perform tasks beyond the assigned ones was more often shown by blue-collar workers (48%) than office workers (34%). This is likely to be the result of the specifics of the work of both groups (the stereotypical perception of blue-collar workers as more vulnerable to unfair employer practices). The most frequently cited reasons for declaring a change of workplace were the desire for higher wages (57%) and the lack of development/promotion opportunities (30%). Interestingly, the feeling of appreciation in one's current place of employment was declared by only 48% of respondents, while 53% said they

felt such appreciation of their job duties from family and friends. The lack of support from the employer in the fight against the effects of inflation was indicated by 76%. The situation at workplaces was assessed positively by 49% of respondents, while 37% chose the answer: neither good nor bad. 73% were not worried about losing their current job although a quarter (23%) reckoned with such a possibility (CBOS Research Announcement, No. 150/2022).

The research results presented above indirectly or directly point to a kind of "intra-organizational rationality" oriented to the withdrawal strategy. According to Robert K. Merton, people who use this type of adaptation remain in society but "do not belong" to it. They have internalized goals (emotionally charged and highly valued) but in their view the available institutional means do not lead to their achievement. It can be hypothesized that in organizations we face a similar phenomenon. Living simultaneously in the organization and "next to it". It is worth noting that the social consequences of labor anomie are reinforced by the management methods and techniques commonly used, which I call the organizational paradox. Here is an illustration of it (Deal, Kennedy, 2000):

Culture of negation – the organization as a mechanism for balancing the interests of employees and management is replaced by the dominance of shareholder power - the belief that the obligations of employers and employees are reciprocal disappears.

Culture of fear – the impassable contractual boundary between workplace and family ceases to exist - it was also a kind of guarantee of employment and pay. The gradual deprivation of this guarantee is causing chaos for many individual biographies.

A culture of cynicism – the linking of managers' income levels to the potential growth of the shares of managed companies is causing the previous commonality of the goals of superiors with those of employees to disappear.

A culture of mistrust – the sense of threat of losing one's job causes a reluctance to share knowledge and to inform superiors of one's ideas.

Culture of anomie – changes in management methods and techniques generate the absence of any cultural order. This forces acceptance of tried-and-true symbols, rituals and values, which contradicts the expected goal of the change.

It poses a serious challenge to theorists and practitioners of organizational life. All the more so because the form of this counterproductive behavior is, as has been emphasized, legal.

4. Summary

The common denominator of the organizational perspectives described by Gareth Morgan (1997) is their metaphorical nature. This leads to certain consequences: on the one hand, the use of metaphor is the result of a way of thinking and a way of seeing that permeates our proper understanding of the world in general. Thus, metaphor influences scientific interests,

the language we use, the way we think and how we externalize ourselves in our daily lives. But on the other hand, metaphors have an important cognitive function - they enable us to perceive the object of study from a particular perspective. Although always one-sided, but allowing to reduce the complexity of organizational processes (Pawnik, 2007). My take on the Polish reality of worker anomie would be the metaphor of "organization as a game". Withdrawal, i.e. being in the organization and at the same time "next to it," constitutes counterproductive legal behavior. Minimizing their scope therefore appears to be far more difficult than creating regulations to reduce the other forms of pathology and organizational dysfunction described in detail in the literature. It leaves open the question of the meaning of the workplace in the conditions of the Polish socio-economic system. It also changes the perspective of the search for methods and techniques for internalizing the "desired organizational culture".

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References

1. Beskid, L., Milic-Czerniak, R., Sufin, Z. (1995). *Polacy a nowa rzeczywistość ekonomiczna. Procesy przystosowania się w mikroskali*. Warszawa: IFiS PAN.
2. Bowling, N., Gruys, M. (2010). Overlooked issues in the conceptualization and measurement of countproductive work behawior. *Human Resource Management Review*, *No. 20*, pp. 54-61.
3. Crozier, M., Friedberga, E. (1994). *Człowiek i system.* Warszawa: PWE.
4. Deal, T., Kennedy, A. (2000). *The New Corporate Cultures. Revitalizing the Workplace After Downsizing, Mergers and Reengineering.* London/New York: EXERE.
5. Filas, S. *Zachowania kontrproduktywne w organizacji*. Retrieved from: https://zawodowysos.pl/zachowania-kontrproduktywne-w-organizacji/, 20 06 2024.
6. Goffman, E. (1981). *Człowiek w teatrze życia codziennego.* Warszawa: PIW.
7. Konecki, K., Tobera, P. (2002). *Szkice z socjologii zarządzania.* Łódź: Wydawnictwo Uniwersytetu Łódzkiego.
8. Kowalewski, K., Moczydłowska, J.M. (2020). *Patologie i dysfunkcje w organizacji.* Warszawa: Difin.

9. Merton, R.K. (1982). *Teoria socjologiczna i struktura społeczna.* Warszawa: PWN.
10. Morawski, W. (1998). *Zmiana instytucjonalna. Społeczeństwo. Gospodarka. Polityka.* Warszawa: PWN.
11. Morgan, G. (1997). *Obrazy organizacji*. Warszawa: PWN.
12. *Nastroje na rynku pracy w listopadzie*. Komunikat z badań CBOS, No 150 (2022).
13. Pawnik, W. (2007). *Organizacja. Zachowania organizacyjne. Perspektywa socjologiczna.* Kraków: Wydawnictwa Naukowo-Dydaktyczne.
14. Strategor (1999). *Zarządzanie firmą: strategie, decyzje, struktury, tożsamość*. Warszawa: PWE.
15. Szmatka, J. (1989), *Małe struktury społeczne. Wstęp do mikrosocjologii strukturalnej*. Warszawa: PWN.
16. Szomburg, J. (1993). Jaki kapitalizm w Polsce? *Przegląd Polityczny*, *numer specjalny*, pp. 7-8.
17. Sztompka, P. (2022). *Socjologia. Analiza społeczeństwa.* Kraków: Znak.
18. Turek, D. (2012). *Kontrproduktywne zachowania pracowników w organizacji. Przejawy, uwarunkowania, ograniczenia.* Warszawa: Difin.
19. *Zaangażowani, ale nie zmotywowani. Polacy w pracy*. Retrieved from: https://media.pracuj.pl/215457-zaangazowani-ale-nie-zmotywowani-polacy-w-pracy, 10.06.2024.
20. Zaborowski, Z. (1991). Podmiotowość, samoświadomość, struktura „ja". *Życie szkoły, No. 4*, pp. 25-38.

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TO BE BETTER – ANOTHER STEP ON THE WAY TO MORE EFFECTIVE IMPLEMENTATION STRATEGY AT UNIVERSITIES

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Purpose: The main objective of the study is to verify the relationship between the factors influencing the strategy implementation process, the degree of achievement of strategic goals (as a measure of the effectiveness of the strategy implementation) and the strategic approach.
Design/methodology/approach: Standardized research questionnaire was used. 152 universities in Poland were subject to the study. The research sample included public and private universities
Findings: At the outset, it should be noted that among the studied sample, the largest number of universities is characterized by an adaptive 36% and a classic 31% strategic approach. In turn, the visionary approach is characteristic of 20% of universities, and the shaping approach to the strategy - only 13%. In the case of the classic approach to strategy, almost 75% of respondents indicated that the level of implementation of strategic goals is at the level of 25 to 74%. However, none of the respondents indicated the level of achievement of the goals at the level of 75 to 100%, which confirms the well-known statements about the variability and unpredictability of the environment of modern universities.
Originality/value: Due to the increasing variability and unpredictability of the environment of contemporary universities and the relatively large number of publications examining the barriers to strategy implementation at universities, it seems that the verification of the relationships between the factors influencing the strategy implementation process, the degree of achieving strategic goals or the strategic approach may increase the percentage of effectively implemented strategies at universities. The article presents the detailed results of the analysis of a questionnaire survey covering the management staff and employees influencing the implementation of the strategy at universities.
Keywords: Higher education, university, strategy, strategy implementation, strategic management.
Category of the paper: Research paper.

1. Introduction

Over the past decades, universities across Europe have undergone a series of profound changes. Due to the specific nature of an institution such as a university, these changes are particularly interesting, and the results of the activities carried out are often even surprising. The literature on the subject also emphasizes the variability, unpredictability and turbulence of the university's external environment, as well as the influence of stakeholder groups. It is indicated that these pressures significantly influenced the management of contemporary universities. It seems reasonable to quote here the words of Bisbee & Miller: "The challenges faced by higher education institutions are becoming larger and more complex and require a continuous line of leaders who can make the changes needed for sustained performance"(Bisbee, 2015). There are also widespread opinions that modern universities are developing a disturbing imbalance with their environment. Often struggling with a significant overload of requirements and a shortage of rapid response capabilities. Traditional university management models, in which collegial decision-making plays an important role, are considered outdated and completely mismatched to the changing environment. The increase in competitiveness, globalization or the influence of the knowledge-based economy also have a significant impact on the management of modern universities. This new dimension of reality forces universities to develop and effectively implement future development concepts. In the light of the above considerations, numerous attempts to change this weak situation can be observed both in the literature on the subject and in the management of the contemporary university. There are numerous empirical as well as theoretical publications (Siegel et al., 2015; Holstein et al., 2016; Deem, 2007; Rothaermel et al., 2007; Buckland et al., 2009) showing that modern universities are moving towards strategic management based on planning, formulation, implementation of strategies and control of implemented activities. In the light of the conducted research, however, it should be emphasized that there is a huge gap between the empirical research conducted in the area of universities and the implemented activities in the real world. As, for example, Taylor & Machado note: this disconnection undermines the ability to formulate effective strategies for their conceptual understanding in terms of how they can be more effective (Taylor et al., 2006).

In the light of the considerations, it seems justified to deepen the research in the presented area in order to propose measures to increase the percentage of successfully implemented strategies at universities. The subject of this study is to verify the relationship between the factors influencing the strategy implementation process, the degree of achievement of strategic goals (as a measure of the effectiveness of the strategy implementation) and the strategic approach. The study used the method of collecting data in an open (explicit) and standardized way. For this purpose, a standardized research questionnaire was used. 152 universities in Poland were subject to the study. The research sample included public and private universities.

2. The necessity to use strategic management at universities

When analyzing the literature on the subject, it can be stated that today when referring to the concept of management, it most often refers to strategic management. Due to the fact that nowadays the concept of strategic management at universities is grossly overused, for the purposes of this study, it was decided to quote a definition that will be the basis for further considerations. Therefore, strategic management is understood as a comprehensive process consisting of many elements that must effectively interact and function together. These elements include (but are not necessarily limited to) institutional culture, strategic planning, leadership, institutional research, resource allocation, financial, personnel and human resource management, leadership, research and academic activities, and considering the needs of its stakeholders, including: in students, employees or companies.

Over the last decades, not only in Europe, but also around the world, a number of changes have been observed, which, to a different extent and with a different frequency, are subject to universities. The need to strengthen the role of universities in shaping the knowledge-based economy (Mosey et al., 2012; Chapple et al., 2012; Rasmussen et al., 2007) the need for commercialization of scientific research (Rothaermel et al., 2007) and (Rasmussen et al., 2015), the development of multidisciplinary institutes, (Mosey et al., 2012), and (Mitchell et al., 2010; Graham et al., 2006; Wilson et al., 2011; Rabin et al., 2015) or the transfer of university technologies (Chapple et al., 2012) are just some of the aspects influencing the change of expectations towards modern universities . Not without significance is also a marked increase in competition on the market of educational services, globalization, or the need to take into account the needs of university stakeholders in the management process. In light of the above, it is indicated that goal-oriented strategic management is of key importance for the success of the university. In the case of universities, it is also important to act in the field of education, research as well as the mobility of employees and students (Bakoğlu et al., 2016). It is well known that the effective implementation of the strategy is of key importance for the development of any organization. Although the literature on the subject is rich in works on strategic management (Buckland et al., 2009) and (Boyce et al., 2008; Sager, 2009; Etzkowitz, 2015) in universities, as well as methods or tools to support this process, there are still numerous examples of universities in the presented area that were not able to implement their strategic plans . It is indicated that this is largely due to inappropriate implementation of the strategy. The problem with the implementation of future development concepts is closely related to the fact that it covers a wide range of issues. It is usually very difficult for management to take into account all the elements, and also requires considerable knowledge and experience in the presented area. The management focuses only on selected aspects, which unfortunately fails in many cases. Because, as Segatto, de Padua, & Martinelli point out, the implementation of the strategy must be a holistic system, focused on the integration of individual components (Segatto

et al., 2013). Ferlie, on the other hand, emphasizes that in most universities the strategy is formalized systematically by more and more professional management (Ferlie et al., 2008), however, in many cases it leads to a "quasi-strategy" (Buckland, 2009).

In the light of the considerations, it should be noted that despite numerous research works, the area of strategic management in universities is still characterized by a research gap. As it has been shown, the percentage of successfully implemented strategies in universities is very low, and the very process of strategy implementation in universities still requires improvement. Therefore, there is a justified necessity and need to study the entity which is the university, as well as to study the relationships between the factors influencing the process of strategy implementation, the degree of achievement of strategic goals and the strategic approach.

3. Operational risk in strategic management

3.1. Method

The considerations presented above indicate the legitimacy of considering the issue of factors influencing the strategy implementation process at universities. Therefore, it is indicated that the analysis of factors should be included in individual stages of the strategy implementation process at universities. This analysis was the basis for the conducted research. Their main goal was to test the relationship between the occurrence of individual factors influencing the strategy implementation process at universities, the degree of achievement of strategic goals (as a measure of the effectiveness of the strategy implementation) and the implemented strategic approach. Due to the nature of the data, testing of these relationships was performed using a difference test and a correlation test.

In the light of the research conducted, the author of this paper would like to draw attention to a significant phenomenon, also articulated in the literature on the subject, referred to as "execution holes". It is still effectively implemented, for reasons that seem irrational, i.e. impossible to explain by the heuristic of behavior or any economic law (Powell, 2004). As J. Radomska rightly points out, in such a case it should be taken into account that the nature of the implemented development concept also has an impact on the implementation of the strategy. This element determines the very process of the strategy implementation, its scope, course and intensity of the influence of factors supporting or hindering the implementation of the adopted development concepts (Radomska, 2014). In the light of the above considerations, it should be noted that the conducted research, in addition to the analysis of the factors influencing the strategy implementation process in universities, will also concern the analysis of the nature of the strategy itself as an element determining not only the way of using resources,

but also the aggressiveness of the actions taken, as well as the comprehensiveness and scope of necessary analyzes. This is confirmed by the results of research showing that the type of the implemented strategy can be treated as a determinant of the achieved results and a factor influencing the competitive position of the organization (Angel, 2008).

With regard to the research objective described above, two research hypotheses have been formulated, which are as follows:

1. *There is a relationship between the occurrence of factors influencing the strategy implementation process at universities and the degree of achieving strategic goals*.
2. *There is a relationship between the degree of achievement of strategic goals at universities and the implemented strategic approach*.

The hypotheses described above were tested as a result of the research. The results are presented later in the study. The research methodology adopted the concept of Dorminey and Mohn according to which a descriptive scale and risk assessment in terms of likelihood and impact should be applied to the risk analysis (Dorminey et al., 2007). The probability has been defined as: 1 – very unlikely, 2 – unlikely, 3 – medium probability, 4 – probable and 5 – almost certain.

In turn, the strength of the impact was determined: 1 – very low impact, 2 – low impact, 3 – medium impact, 4 – high impact and 5 – very high impact. The risk level was calculated as the product of the likelihood of a given factor occurring and the impact assessment (Dorminey et al., 2007).

The starting point for the conducted empirical research was an in-depth analysis of the literature on the subject, mainly research areas concerning factors influencing the process of strategy implementation and strategic management at universities. The result of this analysis was the preparation of a research tool in the form of a questionnaire consisting of three parts. It was the basis for the research. The study was conducted using the PAPI (Paper and Pencil Interview) technique, based on a research questionnaire. The first part concerned the definition of the implemented strategic approach. On the other hand, the second section includes questions concerning the determination of the strength of influence and the probability of 113 factors influencing the strategy implementation process.

Variables determining the significance of a given factor influencing the process of strategy implementation at universities were defined using an ordinal scale. The aim was to obtain information on the factors influencing the strategy implementation process at universities in Poland and the probability of their occurrence in the surveyed organizations. The degree of achievement of strategic goals was also distinguished using an ordinal scale.

The reliability and reliability of the measurement tools was verified by calculating the Cronbach's alpha reliability coefficient for aggregated measures. Due to the fact that the value of the coefficient is 0.93 (Hair et al., 2006), the measurement tools used can be considered reliable.

As it has already been mentioned, the research aimed at identifying the interrelationships between the occurrence of individual factors influencing the strategy implementation process at universities, and the degree of achievement of strategic goals (as a measure of the effectiveness of strategy implementation) and the strategic approach. A closer description is presented below, adopted as the basis for the conducted analyzes. The first area of research was related to the effectiveness of the strategy implementation process defined by the degree of achieving strategic goals. It is presented on a scale from 1 to 5, where:

1 – Means a very low probability (5%),

2 – Unlikely (25%),

3 – Moderately likely (50%),

4 – Probable (75%),

5 – Almost certain (90%).

In the next stage, the data was grouped. The second of the specified areas concerned the implemented strategic approach. The research was based on the questionnaire proposed by Reeves, Haanaes and Sinha (Reeves et al., 2015). The proposed concept makes it possible to forecast changes in the environment, both internal and external (determining how much in advance and with what detail it is possible to forecast the results of the organization, competition dynamics, market expectations and demand) as well as the ability to influence them (determining susceptibility to influences, i.e. the degree of impact to the above factors). Respondents were asked to identify one of the statements that best describes the current strategy implementation practices, the approach to the strategies they intend to implement, and the perception of the university environment. It was assumed that two out of three indications for a specific strategic approach will allow the classification of a university to one of the five specified types (their characteristics are presented below):

Classic - a university is able to predict changes in the environment (the environment is stable), however, it cannot influence them. This approach is based on the classic method of creating and implementing a strategy, assuming a planning approach and the use of quantitative forecasting methods in subsequent stages of planning.

Adaptive - a university cannot predict changes in the environment and cannot influence this environment. This requires universities to react quickly to the diagnosed changes and experiment with the implemented strategy. Close integration between operating activities is essential and the implemented development concept, subject to constant modification.

Visionary - a university has the ability to predict and influence changes in the environment, which gives the opportunity to shape new consumer and market needs. This approach is characterized by the possibility of achieving bold strategic goals. However, the necessity to follow the chosen course and the willingness to engage the necessary resources in the activities is indicated.

Formulating - a university cannot predict changes in the environment, but it can influence them. Shaping the market situation enables universities to maximize benefits and increase their competitive advantage. This approach is based on short-term planning and the flexibility of the organization.

Renewing - an approach characteristic of universities which, due to their weak competitive position, are first forced to undertake actions to overcome the crisis situation, and only in the next steps can they allow themselves to choose a different strategic approach. As a rule, this approach is defensive in nature, primarily focusing on cost reduction and capital protection. In the initial phase, the university implements a short-term strategy whose main goal is survival. After the end of the crisis phase, there is a transition to a long-term strategy.

The third area of research concerned factors influencing the strategy implementation process. The respondents were asked to assess the impact and probability of occurrence of each of the 113 factors classified under three areas: strategy, management and employees, taking into account the four stages of the strategy implementation process: planning, formulation, implementation, and control and monitoring. These areas have been specified on the basis of the adopted research concept based on the assumptions of the aforementioned EFQM model and taking into account the results of pilot studies carried out in universities in Poland. An in-depth analysis of the literature on the subject showed the application value of the EFQM model from the point of view of the strategy implementation process, because the presented model contributes to the integrative development and implementation of the development concept. (Revuelto-Taboada et al., 2011). In addition, it should be noted that the analysis of many research studies on the strategy implementation process allowed to identify areas, also included in the EFQM model, which the author of this paper considered the most important from the perspective of the strategy implementation process, i.e. strategy, management and employees. Additionally, each of the categories has been divided into four stages of the strategy implementation process: planning, formulation, implementation as well as control and monitoring.

From the specified areas and stages of the strategy implementation process, a set of factors constituting its components was developed. The presented factors are treated as formal indicators (determinants of a complex phenomenon), and thus building elements of the presented concept. The table presenting the individual factors influencing the strategy implementation process was presented and discussed in detail in our previous work, it was also an element of the questionnaire.

In the first stage of the quantitative study, the method of collecting data in an open (explicit) and standardized manner was used. For this purpose, a standardized research questionnaire was used. 152 universities in Poland were subject to the study. The research sample included various universities, both public and private. The sample size was determined taking into account the constraints associated with the implementation of the study (difficult availability of people in managerial positions in universities, responsible for the implementation of the strategy).

The research sample accounted for 43% of the population. The list of universities in Poland prepared by the Ministry of Education and Science was used as the survey[1]. The website contains an up-to-date and complete list of both public and private universities in Poland.

The study used the stratified random method, based on dividing the statistical population into subsets, which were distinguished on the basis of features significant for the study. This results in the division of the frame into quantitatively and qualitatively different parts. The drawing of research units within individual subgroups was simple, which means that each unit within a given stratum had the same probability of being found in the sample. Due to the fact that direct drawing of independent samples is performed within each layer in a manner that is separate from the other layers (the set is exhaustive, which means that each element is included in one of the layers). Based on the calculations made for the significance level specified at the level of $\alpha = 0.05$, the level of the presumed maximum fraction error in the main part of the study was set at a level close to 0.1%.

The subject of the study were factors influencing the strategy implementation process, the effectiveness of the strategy implementation process (expressed by the degree of achievement of strategic goals) and the implemented strategic approach. In the next stage, statistical tools were used to analyze the obtained values. The research sample was selected in a disproportionate way. This means that the sample structure does not reflect the general population. Thus, in order to compensate for the inhomogeneous probabilities of the population units entering the sample, the sample weighting was performed. The decrease in the share of the smallest higher education layers was due to their dominance in the population. The respondents in the study were people holding managerial positions who have an impact on the strategy implementation process in universities in Poland.

When summarizing, it should be pointed out that the literature on the subject lacks research results concerning the relationship between a specific type of strategy implemented at universities and the achieved result (Salavou, 2010). There is a certain discrepancy in the presented area, as some researchers argue that the implementation of one classic strategy positively influences the results achieved by the organization (Thornhill et al., 2010). On the other hand, other authors emphasize that combining several development concepts may result in a significant improvement in business results. The analysis of the research on the strategy implementation process allowed for the specification of the areas classified in the EFQM model as the potential category, i.e. those having the greatest impact on the process of implementing development concepts. One can indicate here: management (leadership), employees or strategy (Radomska, 2014). In each of the presented areas, the factors that are its components have been specified.

[1] https://www.gov.pl/web/edukacja-i-nauka/szkolnictwo-wyzsze, 13.11.2023.

3.2. Result and discussion

In order to test the first of the formulated hypotheses, assuming the relationship between the presence of factors influencing the strategy implementation process at universities and the degree of achieving strategic goals, a number of analyzes were carried out, the results of which are discussed in detail later in the study. In the first stage of the research, the overall level of risk was analyzed, broken down into individual target achievement ranges. The level of operational risk was calculated as the product of the average probability of occurrence and the assessment of the impact of all operational risk factors. Figure 1 shows the results obtained for universities in Poland.

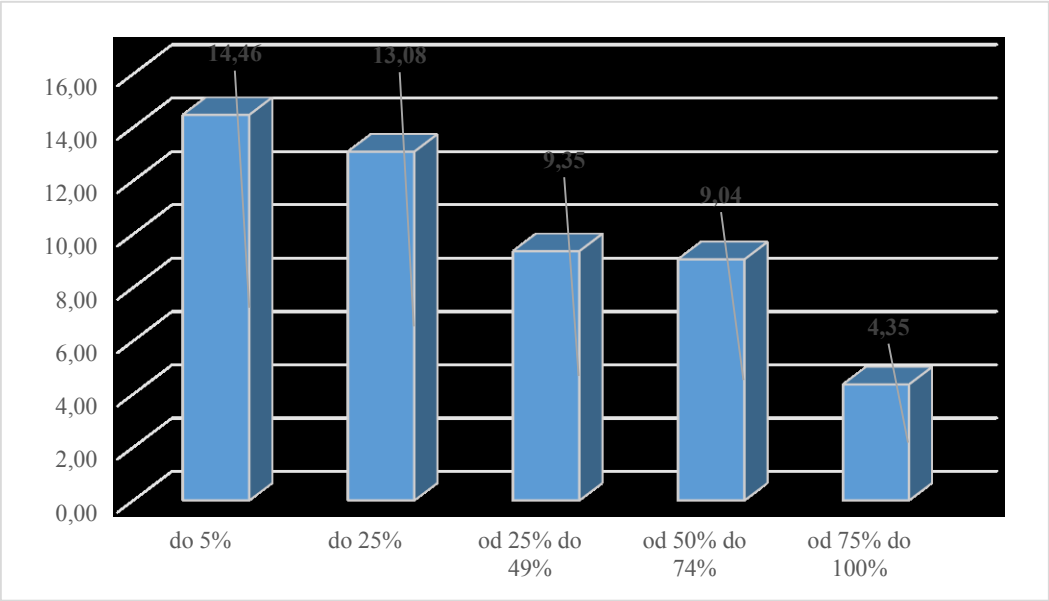

Figure 1. Operational risk level in individual achievement ranges complex strategic goals at universities
Source: Own study.

The analysis of Figure 1 allows for the observation of a certain regularity indicating a decrease in the level of operational risk with a simultaneous increase in the percentage of goals achieved. In the light of the above, it seems that it can be assumed that those universities that demonstrate greater effectiveness in achieving the assumed goals feel less threatened by operational risk factors. This may be related to the elimination and elimination of the negative impact of risk factors, resulting, inter alia, from greater awareness of their existence among universities.

The correlation between the overall level of risk and the degree of achievement of strategic goals was also calculated. The result is presented in Table 1.

Table 1.
Correlation between the overall level of operational risk and the degree of achievement of strategic goals at universities

	The degree of achievement of strategic goals and the level of operational risk (total average)
Pearson's correlation	0,456**
Significance (two-sided)	0,000
N	152

Source: Own study.

The average level of correlation in the case of universities indicates the existence of the assumed correlation and allows for a positive test of the research hypothesis. (Hypothesis No. 1)

In the next stage, an analysis of the correlation between the degree of achievement of strategic goals at universities and the probability and assessment of the occurrence of risk elements, broken down by individual factors, was performed. The obtained results indicate the lack of a statistical correlation with an average strength of the relationship between the degree of achievement of strategic goals and the probability of occurrence of individual risk factors (r = 0.156). On the other hand, there was a statistical correlation between the degree of achievement of statistical goals and the assessment of significance (r = 0.611).

Table 2.
Correlation between the degree of achievement of strategic goals and the probability and assessment of the occurrence of the factor at public and private universities

		Universities	
		Risk factors - probability	**Risk factors - assessment**
The degree of implementation of strategic goals	**Pearson's correlation**	0,156**	0,611**
	Significance (two-sided)	0,054	0,000
	N	152	152

Source: Own study.

Interesting results were obtained by analyzing the relationship between the degree of achievement of strategic goals and the assessment of the impact of risk factors. Significantly statistically positive correlations were found (r = 0.626). The obtained results allow to conclude that in the case of universities, an increase in the assessment of the impact of individual factors on the failure to implement the university's strategy translates into an increase in the degree of implementation of strategic goals. Therefore, it can be concluded that being aware of the high impact of operational risk factors may be used to take actions aimed at reducing it.

In order to obtain more detailed relationships, the correlations between the level of achievement of strategic goals and the areas and stages of operational risk were calculated. The results are presented in Table 3.

The specified correlations are moderate. On the other hand, a positive correlation indicates that with the increase in the level of risk, the degree of achievement of strategic goals increases, which seems to be a quite surprising result. These dependencies are characteristic of the stages:

formulation and implementation of strategies, described in the literature as the most problematic. Therefore, it can be concluded that the management staff of universities is fully aware of the numerous difficulties occurring in these stages of the implementation process, and the higher probability of the emergence of risk factors does not adversely affect the possibility of a satisfactory implementation of development concepts in the indicated areas, management and employees. In light of the above, it seems justified to consider the most sensitive area: management (stages: formulation and implementation of the strategy) and the area: employees (stage: implementation).

Table 3.
Correlations between the level of operational risk for the areas and stages of the strategy implementation process and the degree of achievement of strategic goals at universities

		Universities		
Areas	**Stage**	**Pearson's correlation**	**Significance (two-sided)**	**N**
Strategy	Planning	0,222	0,510	152
	Formulating	0,469	0,106	152
	Implementation	0,555	0,121	152
	Control and monitoring	0,970	0,155	152
Management	Planning	0,959	0,141	152
	Formulating	0,652	0,008	152
	Implementation	0,5768	0,015	152
	Control and monitoring	0,201	0,702	152
Employees	Planning	0,760	0,136	152
	Formulating	0,767	0,233	152
	Implementation	0,570	0,033	152
	Control and monitoring	0,201	0,702	152

Source: Own study.

In the opinion of the author of this paper, the obtained results can be considered interesting, as it would seem that the most critical stages of the strategy implementation process at universities in the area of management and employees are slightly more controlled and measured than, for example, those related to the strategy at all stages of the process. Its implementation. The analysis of the obtained results allows us to accept the research hypothesis only partially.

The second of the proposed hypotheses assumed that the existence of the relationship between the degree of achievement of strategic goals and the strategic approach implemented would be checked at universities. In order to verify the hypothesis, the Kruskal-Wallis difference test was performed for independent samples, which showed the significance level at the level of 0.000. The results are presented in Table 4.

Table 4.
Comparison of the degree of achievement of strategic goals at universities implementing different strategic approaches

Tested variables	Significance level
The degree of achievement of the statistical goals and the implemented strategic approach	0,000*

Source: Own study.

The obtained value of the significance level allows to state that the degree of achievement of strategic goals and the implemented strategic approach are related. In the light of the above, one can accept the hypothesis. Due to the fact that both variables were not nominal, we cannot talk about the direction of this relationship. Interesting, however, is the existence of significant differences.

When analyzing the data, it can be concluded that for the visionary strategy, the average level of achievement of goals, between 50 and 74%, at the level of 77%, and 13% of indications for the highest level from 75% to 100% and the level from 25% to 49%. The lowest number of indications in the visionary strategy was recorded by the lowest target achievement level of 6%. In the light of the obtained results, it can be concluded that the level of achievement of the objectives is high, which is a somewhat surprising result. It is worth recalling here that this type of strategic approach is based on anticipating and initiating changes in the environment.

When analyzing the results obtained for the classic strategic approach, it can be seen that 60% of respondents indicate the level of achievement of goals between 25% and 49%. A very high level of achievement of the goals was indicated by 15% of the respondents from 50 to 74%. Interestingly, none of the respondents indicated the achievement of goals at the level of 75 to 100%, which seems to be an extremely disturbing result. Considering the fact that the basis of this approach is to conduct a detailed strategic analysis and careful planning aimed at predicting changes in the environment, the obtained results confirm the well-known statements about the variability and unpredictability of the environment of contemporary universities.

When analyzing the results obtained for the shaping strategic approach, it can be concluded that the level of achieving goals in this approach is much lower than in the case of previous approaches. Interestingly, none of the respondents indicated the implementation of strategic goals at the level of up to 25% and from 25 to 49%. In turn, the highest level of implementation of strategic goals was indicated by 30% of respondents.

The adaptive strategic approach was indicated by the largest number of respondents. The lowest level of implementation of strategic goals was indicated by as many as 70% of respondents. On the other hand, only 12% of respondents indicated the average level of implementation of strategic goals and 3% each for the achievement of goals at the level of 50 to 74% and 75-100%. The obtained results should not be surprising, as there is no possibility of making predictions and impact on changes in the environment may result in the need to take reactive measures. The chart does not present the answers obtained in the case

of the implementation of the renewing strategy, as this approach was not indicated by any respondent.

3.3. Conclusion

The obtained research results lead to conclusions that will be the subject of further discussion. At the outset, it should be noted that among the studied sample, the largest number of universities is characterized by an adaptive 36% and a classic 31% strategic approach.

In turn, the visionary approach is characteristic of 20% of universities, and the shaping approach to the strategy - only 13%. It should also be emphasized that none of the respondents indicated in the study of renewing the strategic approach. Such differentiation in the approach to the implemented strategy gives the possibility of obtaining heterogeneous information and allows for more complex conclusions. However, it does not provide full representativeness within the specified subgroups. It should be emphasized, however, that the research results indicate the existence of some relationships that can be considered statistically significant. It allows to make some generalizations and to indicate the observed regularities.

One of the subjects of considerations in this study was the search for relationships between the level of operational risk and the degree of achievement of strategic goals. The results of the conducted research indicate the existence of correlation between the specified areas. It is indicated that along with the increase in the level of achievement of the assumed goals, the level of operational risk accompanying these activities decreases.

The second of the formulated hypotheses concerned the study of the relationship between the degree of achievement of strategic goals and the strategic approach. The conducted analyzes allow for the assumption of the hypothesis. The results showed that the visionary strategy is characterized by a high level of implementation of strategic goals. O seems a somewhat surprising result, considering the fact that this type of strategic approach is based on predicting and initiating changes in the environment. In the case of the classic approach to strategy, almost 75% of respondents indicated that the level of implementation of strategic goals is at the level of 25 to 74%. However, none of the respondents indicated the level of achievement of the goals at the level of 75 to 100%, which confirms the well-known statements about the variability and unpredictability of the environment of modern universities. The adaptive strategic approach was indicated by the largest number of respondents. On the other hand, the lowest level of implementation of strategic goals was indicated by as many as 70% of respondents. The obtained results should not be surprising, as the inability to predict and influence changes in the environment may result in the necessity to take reactive measures. When analyzing the results obtained for the shaping strategic approach, it can be concluded that the level of achieving goals in this approach is much lower than in the case of previous approaches.

As it has already been indicated, the conducted research did not confirm all the assumed relationships. There is a link between the implemented approach and the degree to which strategic goals are achieved, primarily pointing to the greater effectiveness of approaches based

on the possibility of predicting changes in the environment. The conducted research also confirms the existence of a relationship between the degree of achieving strategic goals and the level of operational risk.

References

1. Angel, R. (2008). Linking execution with strategy in support functions. *Ivey Business Journal*, pp. 1-2.
2. Bakoğlu, R.A.Z., Öncer, Y.M.L., Güllüoğlu, A.N. (2016). Strategy Development Process in Higher Education: The Case of Marmara University. *Procedia – Social and Behavioral Sciences*, pp. 36-45.
3. Bisbee, D.C., Miller, M.T. (2006). *A Survey of the Literature Related to Executive Succession in Land Grant Universities*. ERIC database, 20.10.2008.
4. Boyce, G. (2008). The social Relevance of Ethics Education in a Global(ising) Era: From Individual Dilemmas to Systemic Crises. *Critical Perspectives on Accounting, Elsevier, vol. 19(2)*, pp. 255-290.
5. Buckland, R. (2009). Private and public sector models for strategies in universities. *British Journal of Management*, pp. 524-536.
6. Chapple, W., Lockett, A., Siegel, D. et al. (2012). Assessing the relative performance of UK university technology transfer offices: Parametric and non-parametric evidence. *Research Policy*, pp. 369-384.
7. Deem, R., Hillyard, S., Reed, M. (2007). *Knowledge, Higher Education and the New Managerialism*. Oxford: Oxford University Press.
8. Dorminey, J., Mohn, R. (2007). A Model for Not-for-Profit Enterprise Risk Management: ERM at the Federal Reserve Bank of Richmond. *Journal of Government Financial Management*, pp. 50-57.
9. Etzkowitz, H. (2015). The entrepreneurial university as a technopole platform. A global phenomen. In: J.T. Miao, P. Benneworth, N.A. Phels (Eds.), *Making 21st century knowledge complexes: technopoles of the world revisited*. New York: Routledge.
10. Ferlie, E., Musselin, C., Andresani, G. (2008). The steering of higher education systems: A public management perspective. *Higher Education*, pp. 325-348.
11. Graham, I.D., Logan, J., Harrison, M.B., Straus, S.E., Tetroe, J., Caswell, W. et al. (2006). Lost in knowledge translation: time for a map? *J Contin Educ Health Prof*., pp. 13-24.
12. Hair, J., Black, W., Anderson, R., Tatham, R. (2006). *Multivariate Data Analysis*. Upper Saddle River, New York: Prentince-Hall International.
13. Holstein, J., Starkey, K., Wright, M. (2016). Strategy and narrative in higher education. *Strategic Organization*, pp. 61-91.

14. Mitchell, S.A., Fisher, C.A., Hastings, C.E., Silverman, L.B., Wallen, G.R. (2010). A thematic analysis of theoretical models for translating science in nursing: mapping the field. *Nurs Outlook*, pp. 287-300.
15. Mosey, S., Wright, M., Clarysse, B. (2012). Transforming traditional university structures for the knowledge economy through multidisciplinary institutes. *Cambridge Journal of Economics*, pp. 587-607.
16. Powell, T. (2004). Strategy, Execution and Idle Rationality. *Journal of Management Research*, pp. 77-80.
17. Rabin, B.A., Brownson, R.C. (2012). Developing the Terminology for Dissemination and Implementation Research. In: R.C. Brownson, G.A. Colditz, E.K. Proctor, (Eds.), *Dissemination and Implementation Research in Health*. New York: Oxford University Press, pp. 23-51.
18. Radomska, J. (2014). Model of Successful Strategy Execution – revising the concept. *Problems of Management in the 21st Century, 9/3*, pp. 213-222.
19. Rasmussen, E., Wright, M. (2015). How can universities facilitate academic spin-offs? An entrepreneurial competency perspective. *Journal of Technology Transfer*, pp. 782-799.
20. Reeves, M., Haanaes, K., Sinha, J. (2015). *Your strategy needs a strategy. How to Choose and Execute the Right Approach*. Massachusetts: Harvard Business Review Press. pp. 215-217.
21. Revuelto-Taboada, L., Canet-Giner, T., Balbastre-Benavent, F. (2011). Quality tools and techniques, EFQM experience model: a critical review and new perspectives. *Total Quality Management and Business Excellence*, pp. 731-732.
22. Rothaermel, F.T., Agung, S.D., Jiang, L. (2007). University entrepreneurship, a taxonomy of the literature. *Industrial and Corporate Change*, pp. 691-791.
23. Sager, T. (2009). Responsibilities of Theorists: The Case of Communicative Planning Theory. *Process in Planning, 72(1)*, pp. 1-51.
24. Salavou, H. (2010). Strategy types of service firms: evidence from Greece. *Management Decision*, pp. 1033-1047.
25. Segatto, M., de Padua, S., Martinelli, D. (2013). Business process management: a systematic approach? *Business Process Management Journal*, pp. 698-714.
26. Siegel, D.S., Wright, M. (2015). Academic entrepreneurship, time for a rethink? *British Journal of Management*, pp. 582-595.
27. Taylor, J., Machado, M.D.L. (2006). Higher education leadership and management: From conflict to interdependence through strategic planning. *Tertiary Education and Management*, pp. 137-160.
28. Thornhill, S., White, R. (2007). Strategic purity: A multiindustry evaluation of pure vs hybrid business strategies. *Strategic Management Journal*, pp. 553-561.
29. Wilson, K.M., Brady, T.J., Lesesne, C. (2011). On behalf of the NCCDPHP Work Group on Translation. An organizing framework for translation in public health: the knowledge to action framework. *Prev Chronic Dis*, *8(2), A46*.

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HOW IT IS POSSIBLE TO BALANCE THE DEVELOPMENT OF THE ENTERPRISE BASED ON THE SITUATION APPROACH IN MANAGEMENT: THE EXAMPLE OF UKRAINE

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Purpose: The purpose of this article is a comprehensive study of the state of balanced development of companies in conditions where their activities are characterized by complexity caused by the influence of many factors; uncertainty due to the low probability of predicting the future in crisis conditions and sudden changes in the parameters characterizing the business environment; volatility, when we observe a high degree of fluctuation in the value of a certain parameter or variable during a certain period of time.
Design/methodology/approach: The methodology is based on the use of factor analysis to study the factors of influence of the external and internal environment on the activity of industrial enterprises, the factors of which are divided into groups of latent variables; the application of the method of piecewise regression analysis, convenient in cases where the dependent variable changes dramatically after reaching a certain critical value, allows you to study such an environment and build scenarios as the paths along which enterprises plan to develop.
Findings: Situational models have been built, which allow obtaining data and cases, which in the future can become the basis for planning the future development of companies. For this, the idea of balanced development of the enterprise is used, which is aimed at determining the conditions of development, when due to the variables of the internal environment, which allow counteracting the determining factors of the external environment. The idea of modeling balanced development is used for enterprises of various industries.
Research limitations/implications: This study offers a comprehensive approach to study the situations that arise due to the environmental impact on the performance of companies, however, there are limitations caused by the analytical capabilities of the researchers in collecting and accessing the necessary information. In addition, today there are situations that are difficult to predict, such as wars and natural disasters. In the future, it is planned to supplement the considered method of situational analysis of the environment with methods of detecting signals of early detection and prevention of adverse situations.
Practical implications: The article examines the practical results of the application of the proposed approach to the analysis of the environment of industrial enterprises using the proposed methods, which allow to study the environment of an individual enterprise and to model scenarios of its potential development with a high level of reliability.
Social implications: The proposed research can have an impact on society, providing methods for studying the environment, which is characterized by complexity, uncertainty, as well as determining forecasts of its variability.

Originality/value: A method of studying situations that arise in the activities of companies due to the uncertainty, complexity and variability of the environment, in which it is difficult to plan future development due to the absence or insufficient information, is proposed. Its application is valuable for gathering information and forming cases, which can later be used to plan the development of companies using artificial intelligence technologies.
Keywords: situational management, scenarios, model, hidden factors, external and internal environment, balanced development, VUCA.
Category of the paper: conceptual paper, case study.

1. Introduction

The trends of modern development are characterized by the VUCA world as well as the need to understand it, anticipate and respond accordingly (Niehaus et al., 2024). Such work is greatly facilitated using the main achievements of management science, which considers various approaches to management, formed during its evolution (Fig. 1).

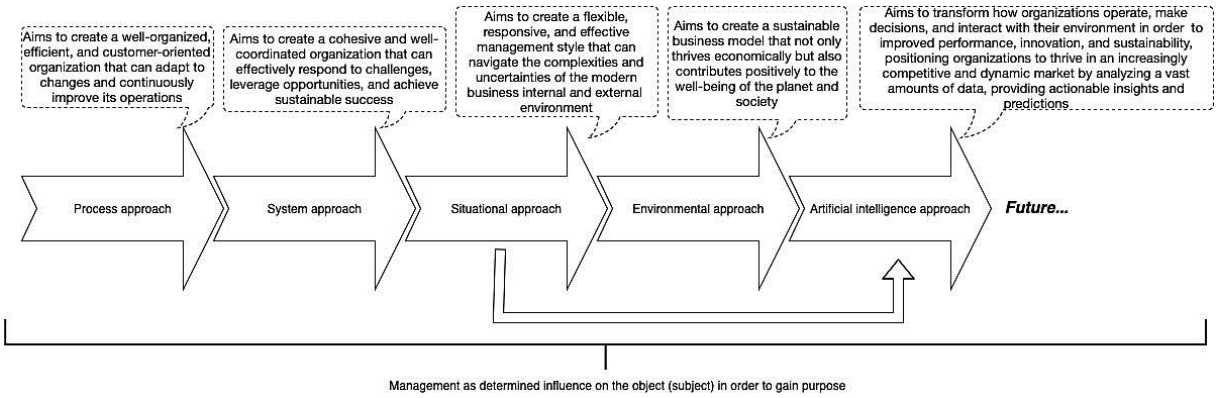

Figure 1. Modern management approaches evolution

Source: created by author.

Transformations that are taking place today in all spheres of economic activity occur because of current actions and the result of prediction (Zgurovsky et al., 2010). In this article, we focus on the situational approach, although we consider it in combination with other approaches to prepare the basis for conducting research on the relevance of situational management in today's conditions.

The emergence of situational approach in management as a result of the development of systems theory was determined by the need to understand what and how affects the system and the effectiveness of its functioning. The study of a wide range of factors made it possible to describe specific situations, or as they are also called "cases", the information base of which today serves as the basis for the development of neural networks and artificial intelligence technologies (Babets et al., 2023), etc.

The ability to consider the organization from the standpoint of an organizational structure capable of responding to the challenges of the environment of its functioning made it possible to adapt activities to modern challenges, such as global warming, digital transformation, natural disasters, wars etc. As a result of this progress, we have the expansion of the fields of new trends affecting arising situations based on artificial intelligence (Vladyko et al., 2022; Psyuk et al., 2024), digital transformation, sustainable development and energy transition (Polyanska et al., 2022, 2023) - this spectrum of changes allows forming a solid basis for predicting future, learning opportunities and planning development perspectives. All this determines the relevance of the study of situation management techniques and their application in practice.

2. Literature review

Scientists who study the problems of situational approach in management unanimously claim that there is no single correct way of enterprise development, because in the conditions of adaptation to the external environment, it is impossible to create such structures, methods, types of organizational order, to consider factors that would be ideal for use for any enterprise, time, goals, tasks, situations, etc. Each management situation corresponds to its optimal requirements for state, strategy, and structure (Woodward, 1965). The central point of the situational approach is the situation, that is, a specific set of circumstances that strongly affect the enterprise at a specific moment in time. Researchers note that to act within the framework of the concept of the general process of management and considering the situational approach, it is necessary to summarize and connect the existing knowledge, to give them the necessary framework, which is possible since a systemic approach using the main methodological provisions regarding situational management (Melnyk, 2009).

To highlight the main theoretical and methodological principles of situational management in modern conditions, we will consider the main provisions that characterize the essence of the specified management category, the prerequisites for its emergence and the peculiarities of its evolution. That could be essential for understanding the sense and relevance of its utilization. The "law of the situation" was first formulated in the early 1920s by Mary Parker Follett (1868-1933). She argued that the manager's effectiveness depends on his possession of the necessary knowledge; but different circumstances call for different knowledge, and, accordingly, different people achieve the greatest success in them: the best leaders become better not because they are endowed with any special leadership qualities, but because they meet the demands of the situation.

The transformation of the situational approach into an influential theoretical position began in the late 1950s based on the development of the main provisions of the theory of open systems to develop a concept that would explain the properties of the organizational structure by the

specifics of its adaptation to the internal and external environment. Researching the issue of situational approach in management, scientists have studied various factors that determine such "situationism". The list of factors included: applied technology (Joan Woodward); organizational structure (Tom Burns, George Stalker); state of the environment (Lawrence and Jay Lorsch); the size of the organization (Derek Pugh, David Hickson, Peter Blau, Richard Shenher) and its strategy (Alfred Chandler, G. Mintzberg, I. Ansoff) etc.

The first work in the field of situational management is the research of T. Burns and J. Stalker, who concluded that each type of economic conditions is characterized by its own organizational structure: for stable conditions - "mechanistic", for changing conditions - "organistic" (Luthans, 1973, p. 133). According to the definitions of this concept by followers, namely by R. Mockler (1971), the situational theory of management is designed to solve practical management tasks. The theory of the organization's life cycle can also be considered from the standpoint of situational approach, since each stage of the life cycle requires appropriate technologies and management tools (Adizes, 1979). It is important to take into account the requirements of a dynamic environment under the influence of which economic processes take place based on the achievement of a certain creativity, that is, the ability to special perception of the situation, which takes into account many of its specific manifestations and at the same time ensures its processing in a creative, not a template mode and ensuring effectiveness in a time close to reality (Thomson, Strickland, 2006). Researchers note that the purpose of situational studies is an empirical study of comparative problem situations, influential factors, alternative scenarios from a set of operating enterprises (Staehle, 1976).

M. Meskon, M. Albert, F. Hedouri (1988) defined the situational approach as a concept that states that the optimal solution is a function of environmental factors in the organization itself (internal variables) and in the surrounding environment (external variables), aimed at management in a specific situation for more effective achievement of organizational goals. In the development of this statement, R. Griffin and V. Yatsura (2001) consider the enterprise as a dynamic structure that changes its activity depending on the state and influences of the external environment, and the uniqueness of each organization based on the collected information allows choosing behaviour that corresponds to a specific situation and its special circumstances. In particular, H. Kuntz and S. O'Donnell (1976) point out that effective management is management based on circumstances, or situational management. Scientists highlighted the need to apply knowledge in a certain field of activity, a practical problem to achieve the best results in a certain situation. Such an interpretation creates conditions under which it is possible to mathematically build a model that will allow describing situations, analysing them and making forecasts.

Considerable attention was paid to the issue of situational approach in the field of human resources development. Situational leadership styles are directly related to different categories of employee maturity (Fiedler, 1964), and the effectiveness of a target group or organization depends on two main factors: the personality of the leader and the degree to which the situation

gives the leader power, control and influence over the situation or, conversely, the degree to which the situation confronts the leader with uncertainty (Nebeker, 1975).

The result of the application of the situational approach in management could be projected into scenario planning, which allows considering alternative conditions of the organization's activity that arise as a result of various factors influence. Researching this issue, scientists claim that a scenario is constructed not with the goal to predict the future or make a forecast, but rather to construct multiple possible stories of future situations (Garvey, 2022). Therefore, scenarios are an important tool of situational management (Cordova-Pozo, Rouwette, 2023). Scenarios are considered as a way of planning successful outcomes of crisis management, in case of unforeseen situations (Eriksson, McConnell, 2011).

The opportunities offered by the situational approach in management have significantly expanded the scope of its application. Considering the elements of the situational approach within the framework of the modern TOGAF universal framework for building the IT architecture of enterprises, it is recommended to supplement the methodology of creating and using practices of building the architecture in accordance with the enterprise transformation plans in the long term and developing the necessary capabilities to support these transformations through situational management technologies (Kornyshovaa, Deneckère, 2022).

It is important to consider that the situational approach creates a situational context for the formation of organisational knowledge and its management (Sense, 2007). As noted earlier in this article, the results of different situations analysing form experience and reduce uncertainty in the management process. The result of knowledge management is a product that can be used to solve difficult situations (Polyanska, Malynka, 2014). Cognitive diversity, determined by the level of professionalism and cognitive abilities of decision-making subjects, can also be balanced by the achievement of the necessary knowledge (Polyanska, Psiuk, 2019). The deepening of the research methods of various aspects of enterprise activity creates a repository of knowledge (Bieda et all, 2023), which can also be used in situational management. Taking this into account is possible when there are relevant methods to research and explain occurring situations.

So, a broad description of situational theoretical models does not allow to fully and accurately describe the real state of organizations and completely rely on practical activities. The presence of situational development models increases the resilience of the business entity to possible changes in the external environment. It allows quickly reorganizing its activities when trends to changes in business conditions are detected as well as orienting scientific-technical and production-marketing activities to the realization of market opportunities for development. Research results have shown that situational awareness supports the continuous development of business models (Gottschalk et al., 2023).

The model, as a tool of management activity, allows to significantly simplify the idea of existing management systems and accurately reproduce the possible reactions of systems to the action of external and internal factors. An analysis of numerous publications devoted to the study and search for ways out of the current economic situation shows that their authors proceed from different models of reality. The model that allows you to manage crisis situations in modern conditions is decisive. Models that reproduce the innovative foundations of domestic development do not give way. Models that ensure sustainable economic development are relevant. More and more attention is paid to the formation of models of competitive development. Of course, each of the models has the right to exist, moreover, each of them allows to reproduce the situation that is characteristic of the conditions of domestic economic development. The choice must be appropriate to the conditions of development of the individual enterprise, and decisions made in the context of development must ensure more than just adaptation to the current operation. In his book "The Challenges of Governance in the 21st Century", Peter Drucker (2001) expresses the idea that to succeed in today's environment, it is necessary not only to adapt to change, but also to manage it. This thesis is also relevant in the study of developmental problems. To adapt to change, most businesses change their operations according to competitors' reactions, consumer demands, technological advancements, etc.

Developing an idea of modelling in situational management we highline the necessity of maintaining the balance of the enterprise as a system consisting of subsystems. Equilibrium is a state that compensates for the influence of the environment and is achieved by establishing a balance within the system and between the system (enterprise) and the environment (Polyanska, 2012). Under the conditions of the application of situational management, the firm's resistance to limiting activities and its effects is formed due to the protective adaptation mechanism. He is entrusted with the task of finding a new equilibrium point because of the separation of the system from the initial equilibrium point, which occurred under the influence of environmental factors.

Thus, today it is important to generalize the scientific principles regarding the application of the situational management approach and its theoretical and methodological justification in solving the problems of the development of industrial enterprises. This will make it possible to reduce the subjective approach to solving problems that hinder the development of industrial enterprises, on the one hand, and on the other hand, to consider the objective requirements of modern development.

3. Article purpose

The purpose of the article is to investigate the conditions of balanced industrial enterprise development with the identification of their potential for necessary changes based on the justification of the relevance of situational management technology usage, in particular, comprehensive analysis methods such as factor analysis, scenario modelling and pieces regression analysis method for the construction of nonlinear dependencies of hidden factors groups of the internal and external environment of enterprises under the study.

4. Methods description

Therefore, today it is important to generalize the theoretical and methodological foundations of the formation of the concept of modern development of industrial enterprises on the basis of situational approach considering the following issues: determination of the prerequisites for situational management, the tasks that it solves in the context of modern development problems; allocation of methodological bases for identifying the situation and factors that cause them, and methods of responding to them, taking into account the achievements of modern management. science and practice.

It is impossible not to agree with the opinion of scientists that no theoretical model provides a complete and accurate description of reality and in practice one should not completely rely on the use of theoretical models. Under such conditions, it is expedient to build a situational model, according to which it becomes possible to make management decisions considering the projected changes both at the level of an individual enterprise, and the macroeconomic situation and the problems that may arise in this case, complementing strategic, long-term management.

The use of mathematical methods for diagnosing the environment in which industrial enterprises operate and plan their development is relevant. One of such methods, which are proposed to be used to study the influence of the external and internal environment on the activities of industrial enterprises, is factor analysis (Iberla, 1980; Oliinyk et al., 2014.). It allows you to process a significant amount of information and identify hidden (latent) factors that characterize the retrospective situation, the consideration of which is the initial condition for modelling the future foundations of development. The data obtained as a result of the assessment are the starting point for building a model of dependence of performance results on the influence of the outlined factors. The model reproduces reality, allows you to combine both the experience of an individual enterprise and modern development trends. The main goal of factor analysis is to reduce the number of variables and determine the structure of interaction between variables, that is, their classification. Such a reduction is achieved by highlighting

hidden common factors, explaining the relationship between the observed variables of the object, that is, instead of the initial set of variables, it becomes possible to analyse data on selected factors, the number of which is much less than the initial number of interrelated variables. The factors selected in this way are called general, since they act on all the features of the object. These factors are hypothetical, hidden, they cannot be measured directly, but the proposed statistical methods allow them to be distinguished.

The application of factor analysis is based on the construction of a matrix of correlation interdependencies between the studied factors and their classification with the future interpretation of the results obtained to identify latent (hidden) factors that determine most of the aggregate variance of data (Khalafyan, 2007). If the output data is written in the form of a matrix $V = (v_{ij})$, where *i* is the number of the feature, and *j* – observation number, its elements, represented as the values of paired correlations of the *R* feature matrix, are calculated using the formula:

$$r_{ik} = \frac{s_{ik}}{s_i s_k} = \frac{\frac{1}{n-1}\sum_{j=1}^{n}(v_{ij} - \bar{v}_i)(v_{kj} - \bar{v}_k)}{\sqrt{\frac{1}{n-1}\sum_{j=1}^{n}(v_{ij} - \bar{v}_i)^2}\sqrt{\frac{1}{n-1}\sum_{j=1}^{n}(v_{kj} - \bar{v}_k)^2}}, \quad (1)$$

where:

n is the number of observations,

$\bar{v}_i = \frac{1}{n}\sum_{j=1}^{n} v_{ij}$ is the mean,

s_i is the standard deviation of the trait v_i,

s_{ik} and is the covariance of the *i*-th and *k*-th features.

The factor model consists in representing the *matrix Z* of standardized observations $z_{ij} = \frac{v_{ij} - \bar{v}_i}{s_i}$ as a product of:

$$Z = AF, \quad (2)$$

where: $F = (f_{pj})$ is the matrix of values of statistically independent latent factors f_p for each observation, and is the $A = (a_{ip})$ matrix of factor loads (factor mapping), which is determined from the relation:

$$R = AA^{\mathrm{T}}. \quad (3)$$

Provided that the factors are independent, f_p the square of the coefficient a_{ip}^2 shows what proportion of the variance of the *i*-th feature is determined by the *p*-th factor, and the sum is the proportion of the total variance of all traits that is determined by $\lambda_p = \sum_{i=1}^{m} a_{ip}^2$ the *p*-th factor.

Note that – are the eigenvalues of the correlation matrix λ_p R, and their sum shows the proportion of the aggregate variance, which is explained by this factor model.

According to the results of the obtained groups of latent factors of the quantitative assessment of the impact of the environment on the activity of the enterprise, a methodical approach is proposed for researching the stability of the industrial enterprise to limiting external and internal influences by balancing the parameters of local models with the help of simulative models (formula 4). This will make it possible to neutralize or reduce the negative effects of the external environment by adjusting or adapting the internal environment according to the parameters of the local model:

$$\begin{cases} Y_i = b_{01} + b_{11}x_{ij} + b_{21}x_{ij}; \\ Y_i' = \gamma_{01} + \gamma_{11}z_1 + \gamma_{21}z_2 + \gamma_{31}z_3 + \gamma_{41}z_4 \end{cases}, \quad (4)$$

where:

Y_i, Y_i' are the resulting indicators of the *i*-th component of the industrial enterprise's potential, calculated according to local models that take into account the relevant influence of the internal Y_i and external Y_i' environment;

x_{ij} – the *j*-th internal factor of the *x*-th component of the industrial enterprise's potential, which affects the change in the resulting indicator;

z_i – external factors affecting the change in the resulting indicator of an industrial enterprise;

b_{ij}, γ_{ij} are model parameters.

In the conditions of dynamic influence of the external environment, the development processes of an industrial enterprise require the preservation of its state of equilibrium, which allows to compensate for negative external influences due to the purposeful use of the existing potential and considering the requirements of the external environment. The study of this condition is proposed to be carried out based on building a model of the sustainability of the development of an industrial enterprise, obtained by balancing the results of the influence of the internal and external environment, reflected in the values of the resulting indicators obtained according to local models:

$$\begin{cases} Y_i = Y_i' \\ b_{01} + b_{11}x_{ij} + b_{21}x_{ij} = \gamma_{01} + \gamma_{11}z_1 + \gamma_{21}z_2 + \gamma_{31}z_3 + \gamma_{41}z_4 \end{cases}. \quad (5)$$

The proposed approach makes it possible to investigate the condition of the sustainability of the enterprise's development and, based on the construction of an analytical model, to identify the necessary resources and directions for improvement of activity.

As a rule, all dependencies that occur in the environment are nonlinear. Therefore, when modelling the relationships characteristic of the processes and phenomena under study, it is advisable to consider nonlinear regression models along with linear regression models.

In particular, the piecewise regression model of estimation is convenient in cases where the dependent variable changes sharply when a certain critical value is reached. Then, until the critical moment is reached, it is advisable to carry out the assessment according to one model, and after reaching it, another one. Piecewise linear regression corresponds to the model (Polyanska, Babenko, 2012):

$$Y = (b_{01} + \mathrm{b}_{11}x_1 + ... + b_{m1}x_m)(Y\langle = Y^*) + (b_{01} + \mathrm{b}_{12}x_1 + ... + b_{m2}x_m)(Y\rangle Y^*), \quad (6)$$

where Y^* is the breakpoint that can be selected by the user or evaluated by the program. For this publication, the indicator of the average value of the integral indicator of efficiency of the investigated enterprises was used.

The application of this approach allows to form a set of alternative scenarios for ensuring the development of the studied enterprises. The choice of the final scenario is conditioned by the values y_c calculated within the framework of the built situational models for each enterprise.

Implementation of the built models allows to assess the efficiency of the studied enterprises and the potential for their development, considering the environment of functioning based on the formula (Polyanska, 2012):

$$\Delta_{\text{розвитку}} = y - y' \quad (7)$$

where y is the value of the integral performance indicator, predicted by the trend model based on its retrospective actual values; y' – the value of the integral performance indicator, predicted according to the built situational model; The sign "-" characterizes the adverse influence of the environment, respectively, the sign "+" is favourable.

Thus, each of these approaches is valuable for assessing the impact of the environment on the performance of enterprises, and their choice and application depend on the goals set by the management, the professionalism and competence of managers involved in this process, and the quality of corporate governance of the enterprise.

5. Research results

The state of the internal environment of the enterprise is a reflection, on the one hand of the influence of the external environment, and on the other hand, of the result of decisions that were made during activity. Today, any business is interested in the following questions: how to achieve stable functioning and ensure development in the future? The answers to these questions require clarification of the following positions: firstly, how the current state of the organization is assessed and, secondly, whether it has the potential for development in the future. It should be noted that in modern conditions, the diagnostic process also requires other tools for analysis and assessment of the condition, which would consider not only the financial aspect of the activity, but also other factors that cause or threaten a crisis state.

The functioning of the enterprise is possible in the presence of certain features, namely the means and objects of labour and capital, which are summarized in the assets of the enterprise. The results of activities, expressed in specific indicators, depend on how efficiently the company uses these assets. Currently, a wide range of indicators is offered for diagnosing the state of enterprises. It is important to choose indicators that characterize the quantitative and qualitative components of development and study the effectiveness of using indicators for assessing the components of the potential of enterprises.

Diagnostics of the internal potential of the enterprise is a complex process that requires significant resources, namely: qualified personnel, information support, financial resources. It requires adherence to certain principles, in particular, content, comprehensiveness, reasonable sufficiency, comparability, taking into account the time aspect, completeness (Sense, 2007, p. 56), and appropriate tools, which ultimately allows you to achieve the greatest effect from its implementation. The stated approach to diagnosing the impact of environmental factors on the activities of enterprise allows to carry out a current review of the potential capabilities of enterprise, to identify the influence of its main components and to adjust them considering the goals of future development. A number of indicators and financial ratios are used to conduct research in successful business management (Walsh, 2006).

Diagnostics of the potential for the development of industrial enterprises is proposed to be carried out using the resource concept, which focuses on the study of the main resource components that ensure effective results of work. As mentioned earlier, each enterprise has a certain potential, which is formed by factors of the external and internal environment. If the enterprise adequately responds to external and internal influences, then it progresses in its development, and if the factors have a negative impact, then a recession is observed, that is, such influences create a certain impulse, because of which the state of the organization resonates (Martinenko, 2006). To date, methods have also been developed and are widely used, which prevent companies from realizing their potential. In particular, the theory of constraints (TOC) developed by E, Goldratt, which is designed to eliminate obstacles and conflicts (Detmer, 1997). Thus, the potential for development of enterprise is formed under the influence of factors of the external and internal environment, considering a set of characteristics, indicators and properties that allow to fully use its capabilities to ensure the satisfaction of the relevant social need for goods for the future and the possibility of achieving the set goals. Since the current conditions of activity of enterprises are quite difficult, the range of key factors in the formation of their potential is also expanding.

However, this is not enough, it is necessary to manage changes on the way to creating a new quality, considering the existing conditions and potential opportunities. In view of the above, today the issue of choosing such a model of development remains relevant, which would allow to combine the conceptual foundations of future development, focused on a more complete and effective use of the existing potential, and local models of development, which allow balancing

internal reserves of activity in accordance with the changes that occur in the environment of functioning of enterprises.

Factor analysis was used to build scenario models for the development of oil refinery, gas supply and petrochemical enterprises. The tables below present the indicators by internal latent factors influencing the activities of gas supply enterprise (Table 1); oil refinery enterprise (Table 2) and petrochemical enterprise (Table 3).

Table 1.
Classification of indicators by internal latent factors influencing the activities of gas supply enterprise

f_1	f_2	f_3	f_4
Cost of basic funds (0.91) Basic funds wear level (-0.899) Labor productivity (0.85) Inventory turnover (0.95) Intellectual Capital (0.95)	Actual rate of return (0.96) return on assets involved (0.945) Return on sales (0.709) The anti-crisis behaviour Index (0.802)	Share of borrowed Capital in assets (-0.76) Inventory volume (0.89) Administrative expenses (-0.83)	Return on equity (0.88) Intangible assets (0.72)

Source: own work.

Table 2.
Classification of indicators by internal latent factors influencing the activities of oil refinery enterprise

f_1	f_2	f_3	f_4
Cost of basic funds (0.71) Basic funds wear level (-0.73) Actual rate of return (-0.98) Return on equity (-0.95) Return on assets involved (-0.98)	Share of borrowed capital in assets (0.70) Return on sales (0.71) Inventory volume (0.81) Inventory turnover (-.95) Copyright (0.83) Intangible assets (0.81)	Labor productivity (0.91) The index of anti-crisis behaviour (0.87)	Level of depreciation of capital (0.61) Profitability of sales (0.62)

Source: own work.

Table 3.
Classification of indicators by internal latent factors influencing the activities petrochemical enterprise

f_1	f_2	f_3	f_4
Cost of basic funds (0.89) Basic funds wear level (0.85) Volume of processed raw materials (0.82) Return on assets involved (0.9) Profitability of sales (0.96) The index of anti-crisis behaviour (-0.91) Administrative expenses (-0.97) Intellectual potential (0.91)	Share of borrowed capital in assets (-0.74) Return on equity (0.91) Actual rate of return (0.99)	Labor productivity (0.94)	Inventory volume (-0.95) Inventory turnover (0.79)

Source: own work.

Relatively, the Table 4 presents the indicators by external latent factors influencing the activities of industrial enterprises.

Table 4.
Classification of indicators by external latent factors influencing the activities of domestic industrial enterprises

F_1	F_2	F_3	F_4
Capital investment growth rate (0.82); Export growth rate (0.92); Import growth rate (0.92); Index of industrial production (0.86); Labor productivity (0.967)	Number of industrial Enterprises (0.91); Degree of wear of basic funds (0.85); Exchange rate (0.83); gas price (0.85)	Share of loss-making Enterprises (-0.81); Creation of added value in industry (0.71); Introduction of new technological processes (-0.77); Euro exchange rates (-0.88)	The number of Industrial enterprises engaged in innovation (0.86); Types of innovative products were introduced (0.54)
The proportion of variance of all traits caused by *the p-th factor*			
29	30	18	11

Source: own work.

Its application to identify the influence of the operating environment on the efficiency of investigated enterprises allows study the activity performance results. To avoid the structural peculiarities in the working out of situational model as one of most impactful factors of situational management, it was chosen the enterprises of PJSC (public joint-stock company) form. The sample considering of oil refinery enterprise allowed to obtain the following results:

- the influence of factors of the internal environment of the researched enterprise on its efficiency is insignificant, which can be seen from the parameters of the obtained mathematical dependencies:

$$y = 0{,}2795 + 0{,}03366\ f_4 \tag{8}$$

where f_4 is the latent factor, which covers a group of indicators: the level of depreciation of fixed assets, profitability of sales (Table 2).

The adequacy of this model is characterized by the following coefficients: R = 0.509; R^2 =0.259 (p – $level(f_4)=0{,}198>0{,}05$), indicating that it cannot be used to describe a situation;
– somewhat different results characterize the influence of the external environment on the efficiency of enterprise, in particular, the obtained dependencies demonstrate the following:

$$y = 0{,}28 + 0{,}04F_1 – 0{,}03F_3 \tag{9}$$

where:
F_1 is the latent factor, which covers a group of indicators: growth rate of capital investments; export growth rate; import growth rate; index of industrial production; labour productivity; F_3 latent factor, which covers a group of indicators: the share of unprofitable enterprises; creation of added value in industry; introduction of new technological processes; euro exchange rate (Table 4).

The adequacy of this model is characterized by the following coefficients: R = 0.75, R^2 = 0.554 (c; p – $level(F_3)=0{,}218>0{,}05$), which indicate that it cannot be used to describe the situation, but it demonstrates a significant influence of the external environment on the efficiency of the studied enterprise (Tables 5-6).

Table 5.
Influence of the internal environment on the efficiency of oil refinery enterprise

N=8	Model: Regression R=0,508, R2=0,258; F(1; 6)=2.0968, p<0.19777; Error 0.06680					
	Beta	**Standard error Beta**	**Into**	**Standard error V**	**t(3)**	**p – level**
Intersection			*0,279515*	*0,023617*	*11,83524*	*0,000022*
f4	0,508885	0,351434	0,036559	0,025248	1,44802	0,197772

Source: own work.

Table 6.
Influence of the external environment on the efficiency of oil refinery enterprise

N=8	Model: Regression R=0,99897, R2=0,9389, F(4; 3)=11,527<0,03636; Error 0.37755					
	Beta	**Standard error Beta**	**In**	**Standard error V**	**t(3)**	**p – level**
Intersection			0,277961	0,020121	13,81480	0,000036
F1	0,605244	0,298613	0,041437	0,020444	2,02685	0,098506
F3	-0,420273	0,298613	-0,028431	0,020201	-1,40742	0,218325

Source: own work.

Thus, the situation that is developing in the activities of oil refinery enterprise is difficult to predict, largely dependent on the external environment. The obtained results allow us to conclude that its efficiency and further prospects for development are associated with changes that not only relate to the activities of the enterprise, but also depend on the decisions that will be made in the context of stabilizing the activities of domestic refineries. And the settlement of issues mainly in the political and administrative spheres would significantly contribute to the promotion of the domestic energy sector to the European market and would be an impetus for effective economic reforms.

Another enterprise that we have chosen for research belongs to the field of gas supply. The activities of these enterprises are significantly influenced by factors of the internal, external and internal environment.

Based on the use of factor analysis (Table 1), a model for gas supply enterprise was built, according to which the influence of the operating environment on its activities can be represented by the following equations:

$$\begin{bmatrix} y = 0{,}241 + 0{,}032 f_4 + 0{,}025 f_2 \\ y = 0{,}239 + 0{,}037 F_1 \end{bmatrix}, \tag{10}$$

where F_1 is the latent factor, which covers a group of indicators: growth rate of capital investments; export growth rate; import growth rate; index of industrial production; labour productivity; f_2 – latent factor, which covers a group of indicators: actual rate of return; profitability of assets involved; profitability of sales; sub-index of anti-crisis behaviour; f_4 – latent factor, which covers a group of indicators: return on equity; intangible assets.

The efficiency of a given enterprise depends on a group of latent factors f_2 and f_4, characterizing the internal environment (R = 0.877; R^2 = 0,769, p – $level(f_4)=0{,}023<0{,}05$; p – $level(f_2)=0{,}05\leq 0{,}05$). The influence of the external environment is determined by a group

of latent factors $F_1(R = 0.857; R^2 = 0.69; p - level(F_1)=0,01<0,05)$, while the influence of the external environment of the enterprise's functioning on the selected latent factors of the internal environment f_2, f_4 can be represented using the following mathematical model:

$$f_2 = -0,008 - 0,623F_3 + 0,504F_1 \quad (11)$$

The adequacy of this model is characterized by the following coefficients: R =0.857; R^2 = 0.734, ($p - level(F_3)=0,035<0,05; F_1=0,07$), i.e. it can be used to describe the situation of predicting future development trends;

– the description of the influence of the external environment on the internal latent factor f_4 can be represented by the equation:

$$f_4 = 0,05 + 0,567F_4 + 0,4774F_1 + 0,32F_3 \quad (12)$$

The adequacy of this model is characterized by the following coefficients: R =0.85; R^2 =0.723, ($p - level(F_1,F_3,F_4)=0,131;0,257;0,119>0,05$), i.e. it is inappropriate to use it for forecasting (Tables 7-8).

Table 7.
Influence of the internal environment (f_2, f_4) on the efficiency of gas supply enter

N=8	Model: Regression R=0,876871, R2=0,7689; F(2; 5)=8.3180, p<0.02567; Error 0.02653					
	Beta	Standard error Beta	In	Standard error V	t(3)	p – level
Intersection			*0,241433*	*0,009379*	*25,74281*	*0,000002*
f_2	0,541214	0,214986	0,025240	0,010026	2,51743	0,053342
f_4	*0,689922*	*0,214986*	*0,032176*	*0,010026*	*3,20914*	*0,023751*

Source: own work.

Table 8.
Influence of the external environment (F_1) on the efficiency of gas supply enter

N=8	Model: Regression R=0,8302, R2=0,6893; F(1; 6)=13.309, p<0.01073; Error 0.02808					
	Beta	Standard error Beta	In	Standard error V	t(3)	p – level
Intersection			0,239083	0,009949	24,03192	0,00000
F1	0,830222	0,227571	0,036898	0,010114	3,64819	0,010729

Source: own work.

Since the influence of the external environment on the activities of this enterprise is determined indirectly through the influence of the internal environment, the use of linear dependencies does not allow to fully reflect such influence. In this case, it is expedient to use nonlinear dependencies, in which the latent factor f_2 is represented through the influence of latent environmental factors. The method of piecewise linear regression allowed to build the following model, which considers two alternative options for development for the studied enterprise (Tables 9-11):

$$y = \begin{cases} 0,175 - 0,055f_4 + 0,043F_1 + 0,017F_3 \; if \; y_c \leq 0,241; \\ 0,223 + 0,034f_4 + 0,062F_1 - 0,01F_3, \; if \; y_c \rangle 0,241, \end{cases} \quad (13)$$

where F_3 is the latent factor, which covers a group of indicators: the share of loss-making enterprises; creation of added value in industry, introduction of new technological processes; euro exchange rate; y_c – in the observable, which is calculated as the predicted value of the integral indicator of efficiency of enterprises.

Table 9.
Influence of the external environment (F_1, F_3, F_4) on the internal environment (f_4) of gas supply enter

N=8	Model: Regression R=0,8504, R2=0,723; F(1; 6)=3.4824, p <0.12969; Error 0.69608					
	Beta	Standard error Beta	In	Standard error V	t(3)	p – level
Intersection			0,0512	0,2584	0,2033	0,8488
F1	0,500601	0,264876	0,477062	0,252421	1,889946	0,131759
F3	0,348274	0,263793	0,327942	0,248392	1,320257	0,257229
F4	0,348274	0,263793	0,327942	0,248392	1,320257	0,257229

Source: own work.

Table 10.
Influence of the external environment (F_1, F_3) on the internal environment (f_2) of gas supply enter

N=8	Model: Regression R=0,8565, R2=0,7337; F(2; 5)=6.8876, p<0.036; Error 0.6106					
	Beta	Standard error Beta	In	Standard error V	t (3)	p – level
Intersection			-0,008342	0,216505	-0,03853	0,970757
F1	0,529424	0,230843	0,504529	0,219988	2,29344	0,070347
F3	*-0,661565*	*0,230843*	*-0,622942*	*0,227366*	*-2,86587*	*0,035164*

Source: own work.

Table 11.
Parameters of the scenario model of gas supply enter

N=8	Model: piecewise regression with a break point Dependent variables: R=0.99822, variance: 99.645%								
	Const. B	f_4	F_1	F_3	Const. B	f_4	F_1	F_3	Breaking Point
Score	0,175314	-0,054717	0,043362	0,07413	0,222565	0,033870	0,061511	-0,00115	0,241433

Source: own work.

The statistical characteristics of this model (R^2 = 0,996 Fisher's statistics F = 280,4, p = 0,000013 standard deviation of residuals s_{er} = 0,027) indicate that the constructed models can be used to predict the impact of the environment on the efficiency of the studied enterprise.

The first variant of the model makes it possible to predict the value of the integral performance indicator under unfavourable conditions, namely, when the predicted value of the integral performance indicator (y_c) is less than the value established by the model. The second option considers an optimistic forecast in a more favourable situation for enterprises at the macro and micro levels.

Thus, the built model of development of gas supply enter describes alternative options for the influence of the external and internal environment of the enterprise's functioning on the integral indicator of efficiency. It allows predicting the influence of factors on the value of this indicator based on considering the potential capabilities of the enterprise to achieve its optimistic and pessimistic trends. Provided that the predicted value $y_c \le 0{,}241$ is reached. The efficiency of the enterprise will depend on the return on equity, intangible assets. As for the external environment, the growth rate of capital investment will have an impact; export growth rate; import growth rate; index of industrial production; labour productivity in industry, as well as such qualitative indicators as the share of unprofitable enterprises; creation of added value in industry; introduction of new technological processes.

A slightly different situation is expected provided that the forecasted value is achieved $y_c \rangle 0{,}241$, and this difference lies in the inverse dependence on such macroeconomic indicators as the share of loss-making enterprises, creation of added value in industry, introduction of new technological processes, euro exchange rate. Of course, improving the efficiency of gas industry enterprises depends on the state of industrial enterprises, which are the main consumers of gas. It is also clear that that the introduction of new technological processes requires additional financial resources, which may lead to a decrease in the efficiency of the enterprise in the short term. Therefore, considering these trends can have a significant impact on the value of the integral performance indicator, and therefore the formation of potential opportunities for future development.

It should be noted that the situation is difficult not only for enterprises in the fuel and energy sector, but also for other industries. Since the carried-out study of the environment of functioning of enterprises of the petrochemical industrial complex, a scenario model of development has been built, which indicates the dependence of the potential opportunities for their development on the technological factor, innovation activity and competitive advantages of products in comparison with imported analogues.

The studies of the influence of the environment on the activities of petrochemical enterprise, carried out with the help of factor analysis, allowed to obtain the following results:
– the efficiency of the specified enterprise through the influence of factors of the internal environment can be represented with the help of dependence:

$$y = 0{,}2657 + 0{,}043 f_2 \qquad (14)$$

where f_2 is the latent factor, which includes the indicator of the share of borrowed capital in assets, return on equity, and the actual rate of return.

The adequacy of this model is characterized by the following coefficients: $R = 0.85$; $R^2 = 0.72$ ($p - level(f_2) = 0{,}008 < 0{,}05$), i.e. it can be used to describe the situation. At the same time, the latent factor f_2 is most influenced by those environmental factors that are grouped into a latent group F_4. The mathematical dependence of such an influence can be represented by the equation:

$$f_2 = -0{,}131 - 0{,}789F_4 \quad (15)$$

The adequacy of this model is characterized by the following coefficients: R = 0.731; R^2 = 0.53 (p – $level(F_4)=0{,}039<0{,}05$), i.e. it allows detecting an external influence, so its coefficient presented in the model can be used to predict the influence of an internal factor f_2;
– the study of the influence of the external environment on the efficiency of the researched enterprise demonstrates the following dependence:

$$y = 0{,}261 - 0{,}029F_4 \quad (16)$$

The adequacy of this model is characterized by the following coefficients: R = 0.537; R^2 = 0.288 (p – $level(F_4)=0{,}17>0{,}05$), i.e. it cannot be used to describe the situation. In this case, it can be concluded that the latent factor F_4 does not have a direct impact on the efficiency of the enterprise but affects through the internal environment.

As mentioned above, since the influence of the external environment on the activities of this enterprise is determined indirectly through the influence of the internal environment, the use of linear dependencies does not allow to fully reflect such influence. In this case, it is advisable to use nonlinear dependencies, which can be represented by the equation (Tables 11-16).

$$y = \begin{cases} 0{,}182 - 0{,}051f_2 - 0{,}077F_4, \ if \ \mathrm{y_c} \le 0{,}266; \\ 0{,}304 - 0{,}012f_2 - 0{,}007F_4, \ if \ \mathrm{y_c})0{,}266, \end{cases} \quad (17)$$

where F_4 is the latent factor, which covers the macroeconomic indicators presented in Table 3, the number of industrial enterprises engaged in innovations, the number of introduced types of innovative products.

Table 11.
Influence of the internal environment on the efficiency of petrochemical enterprise

N=8	Model: Regression R=0,9587, R2=0,919149; F(4; 3)=8.5264, p<0.05469; Error 0.02182					
	Beta	**Standard error Beta**	**In**	**Standard error V**	**t(3)**	**p – level**
Intersection			*0,272468*	*0,008433*	*32,30859*	*0,000065*
f_1	-0,786275	0,293694	-0,039492	0,014751	-2,67719	0,075228
f_2	*0,006135*	*0,180448*	*0,050032*	*0,009063*	*5,52035*	*0,011709*
f_3	-0,689242	0,350225	-0,038132	0,019376	-1,96800	0,143727
f_4	0,3314221	0,240292	0,016646	0,012069	1,37924	0,261655

Note: Italics indicate significant factors.

Source: own work.

Table 12.
Influence of f2 internal environment on the efficiency of petrochemical enterprise

N=8	Model: Regression R=0,8487, R2=0,7203; F(1; 6)=15.453, p<0.00770; Error 0.02869					
	Beta	**Standard error Beta**	**In**	**Standard error V**	**t (3)**	**p – level**
Intersection			*0,265756*	*0,010144*	*26,19965*	*0,000000*
f_2	*0,848717*	*0,215901*	*0,042628*	*0,010844*	*3,93105*	*0,007703*

Note: Italics indicate significant factors.

Source: own work.

Table 13.
Influence of F4 external environment on the efficiency of petrochemical enterprise

N=8	Model: Regression R=0,5369, R2=0,2883; F(1; 6)=2.4308, p<0.1699; Error 0.04577					
	Beta	**Standard error Beta**	**In**	**Standard error V**	**t (3)**	**p – level**
Intersection			*0,260923*	*0,016475*	*15,83755*	*0,000004*
F4	-0,536959	0,344402	-0,029097	0,018663	-1,55911	0,169986

Note: Italics indicate significant factors.

Source: own work.

Table 14.
Influence of F4 of the external environment on the f2 of the internal environment of petrochemical enterprise

N=8	Model: Regression R=0,7309, R2=0,5342; F(1; 6)=6.8817, p<0.03941; Error 0.7372					
	Beta	**Standard error Beta**	**In**	**Standard error V**	**t (3)**	**p – level**
Intersection			-0,130978	0,265365	-0,49358	0,639151
F4	-0,730907	0,278620	-0,788570	0,300601	-2,62331	0,039411

Note: Italics indicate significant factors.

Source: own work.

Table 15.
Parameters of the scenario model of petrochemical enterprise

N=8	Model: piecewise regression with a break point Dependent variables: R=0.97057, variance: 94.201%						
	Const. B	**f2**	**F4**	**Const. B**	**f2**	**F4**	**Breaking Point**
Score	0,181700	-0,051480	-0,076666	0,303955	-0,012188	-0,007247	0,265756

Source: own work.

The statistical characteristics of this model (R^2 = 0,942 Fisher's statistics $F(6,2)$ = 16,2; p = 0,0035 standard deviation of residuals (s_{er} = 0,012) indicate that the constructed models can be used to predict the influence of the environment on the efficiency of the enterprise under study.

The developed mathematical models of development of enterprises in the petrochemical industry demonstrate pessimistic and optimistic variants of development, considering the situation both in the internal environment (latent factor f_2) and at the macro level (latent factor F_4).

The application of the scenario approach has formed a set of alternative scenarios for ensuring the development of the studied enterprises. The choice of the final scenario is conditioned y_c by the values calculated within the framework of the built situational models for each considered enterprise.

Implementation of the built models allows assessing the efficiency of the studied enterprises and the potential for their development, considering the environment of functioning using the formula 7. Table 17 estimates the expected value of the integral indicator of efficiency and development potential of the studied enterprises.

Table 17.
Assessment of the development potential of an industrial enterprise

Projected values of the integral indicator of enterprise efficiency	Petrochemical enterprise $y_c > 0{,}266$		Gas supply enterprise $y_c > 0{,}241$	
	Base year	Predicted year	Base year	Predicted year
y	0,347	0,365	0,276	0,286
y'	0,294	0,292	0,252	0,254
$\Delta_{development}$	-0,053	-0,073	-0,024	-0,032

Notes: y_c – is the average value of the efficiency index of the studied enterprises.

Source: own work.

The obtained results allow us to summarize that the assessment, carried out according to the optimistic model in accordance with $y > y_c$ the condition, characterizes unfavourable development trends for the studied enterprises, namely, that the influence of the environment reduces their efficiency. Such a conclusion determined the need to substantiate a set of measures aimed at improving the efficiency of enterprises.

The way out should be sought in new forms and methods of economic activity, considering the real state of enterprises and situations that limit their development or create favourable conditions for it. It is important to reduce the subjective factor in the formation and implementation of an alternative variant of development, which is possible based on the use of the built scenario models of development, the implementation of which is proposed with the help of the presented mechanism of development which requires to be developed for specific situation.

6. Discussions

The article is not without certain limitations, which are determined by the situational nature of the results and the possibilities of their use. The list of latent factors selected for analysis is debatable. Their list may vary depending on the industry and characteristics of the enterprise under study. In the article, the resulting indicator is defined as an integral indicator of efficiency, which we did not calculate within the scope of this article but took it from the results of previous studies. Another indicator can be chosen as the resulting, the achievement of which is a necessary condition for the development of the enterprise. Approaches to modelling can also be different, but in this article, we have chosen a piecewise regression dependence, which, in our opinion, is the most suitable for the situations of the world's crisis.

The model of piecewise regression scenario modelling is proposed for use in crisis situations, when it is necessary to study indicators whose values change in accordance with new conditions, and dependencies and forecasts of which are formed based on historical data and cannot be used to model future situations. Data on the activity of industrial enterprises during the crisis period of 2008-2009 were used for the research. During this period, we observed significant changes in the results of the enterprises' activities and tried to investigate and

consider the trends of their development in the formation of future scenarios. In our further research, we plan to apply the research methodology developed and discussed in the article on the balanced development of industrial enterprises in the conditions of post-war recovery in Ukraine. This technique can also be used to form development scenarios for enterprises that have experienced crisis phenomena, which were reflected in the results of their activities.

7. Conclusions and recommendations

Thus, today it is important to further develop the idea of a situational approach in management, which allows collecting and accumulating valuable information and data about the business environment and business results of companies. In the era of artificial intelligence, this is a valuable source of modelling future situations and predictions. The application of the scenario modelling method will allow reducing the subjective approach to the assessment of problems that hinder the development of enterprises, on the one hand, and on the other hand, to consider objective requirements for planning of future development. The article defines groups of latent factors of the internal and external environment, which are used in factor analysis to identify hidden, implicit variables that can influence economic processes and results. Considering the specifics of the studied enterprises, the conditions of their balanced development, which is achieved by identifying the indirect influence of the external environment of companies on the indicators of the state of the internal environment, are substantiated. The application of mathematical methods for checking the adequacy of the obtained modelling results determined a sufficient level of their ability to assess the situation due to the identified hidden variables for the enterprises of the petrochemical and gas supply industries. A sufficiently low level of reliability of using the results of the situation assessment based on the obtained models was determined for the oil refining enterprise. The relevance of the situational approach in management, which aims to consider various situations, analyse them and form a repository of knowledge for decision-making in the conditions of the influence of the external and internal environment on activity, is summarized. The application of scenario modelling tools made it possible to construct non-linear dependences of enterprise efficiency on internal and external environmental factors based on the selection of optimistic and pessimistic forecasts. The results of calculations based on the built models allow determining the potential of future enterprises development, as well as identifying weaknesses and obstacles on this path. The use of examples of enterprises of various industries allowed us to trace how the specifics of the enterprise's activity and environmental factors interact with each other. The obtained results can serve as an analytical basis for making decisions about managing activities in conditions of uncertainty. We plan to conduct further research in the direction of applied application of situational approach technologies in identifying potential risks in management.

References

1. Babets., D., Sdvyzhkova, O., Dyczko., A., Gliwiński, Ł. (2023): Optimization of support parameters for reusable mining excavations based on a neuro-heuristic prognostic model. *Mining Machines, 41(3)*, pp. 200-211. Retrieved from: https://doi.org/10.32056/KOMAG2023.3.5.
2. Bieda, B., Sala, D., Polyanska, A., Babets, D., Dychkovskyi, R. (2023). Knowledge management in organisation on the base of using the hybrid methods of uncertainty. *Scientific Papers of Silesian University of Technology, Organization and Management, 187*, pp. 55-74.
3. Cordova-Pozo, K., Rouwette, E.A.J.A. (2023). Types of scenario planning and their effectiveness: A review of reviews. *Futures*, *149, 103153*. Retrieved from: https://doi.org/10.1016/j.futures.2023.103153 .
4. Detmer, H.W. (1997). Goldratt's Theory of Constraints. A System Approach to Continuous Improvement. *ASQ Quality Press*, p. 378.
5. *Development of industrial enterprises based on situational management: theory and methodology: thesis* (2012). Dr. Econ. Sciences: specialist 08.00.04. Economics and management of enterprises (by types of economic activity), p. 496.
6. Drucker, P. (2001). *The Challenges of Governance in the 21st Century*. HarperCollins Publishers Inc., p. 207.
7. Eriksson, K., McConnell, A. (2011). Contingency planning for crisis management: Recipe for success or political fantasy? *Policy and Society*, *30(2)*, pp. 89-99. Retrieved from: https://doi.org/10.1016/j.polsoc.2011.03.004
8. Fiedler, F. (1964). A Contingency Model of Leadership Effectiveness. In: L. Berkowitz (Ed.), *Advances in Experimental Social Psychology, 1*, pp. 149-190. Retrieved from: https://doi.org/10.1016/S0065-2601(08)60051-9.
9. Garvey, B. (2022). *Scenarios: What Are They, Why Are They Useful and How Can We Best Use Them?* Chapter, pp. 115-149.
10. Gottschalk, S., Yigitbas, E., Nowosad, A., Engels, G. (2023). Continuous situation specific development of business models: knowledge provision, method composition, and method enactment. *Software and Systems Modelling, 22*, pp. 47-73. Retrieved from: https://doi.org/10.1007/s10270-022-01018-9.
11. Griffin, R., Yatsura, V. (2001). *Fundamentals of management* [in Ukrainian]. BaK.
12. Ichak, A. (1979). Organizational Passages-diagnosing and Treating life cycle Problems Of Organization. *Organizational Dynamics*, *8(1)*, pp. 3-25.
13. Khalafyan, A.A. (2007). *STATISTICA 6. Statistical data analysis*, [textbook]; 3rd ed. Binom-Press LLC, p. 512.

14. Koontz, H., O'Donnell, C.J. (1976). *Management: a systems and contingency analysis of managerial functions*. New York: McGraw-Hill, p. 824.
15. Kornyshovaa, E., Deneckère, R. (2022). A Proposal of a Situational Approach for Enterprise Architecture Frameworks: Application to TOGAF. *Procedia Computer Science*, *207*, pp. 3493-3500.
16. Luthans, F. (1973). The contingency theory of management: A path out of the jungle. *Business Horizons, 16(3)*, pp. 67-72.
17. Martinenko, V. (2006). *Strategy for the livelihood of industrial enterprises*. Centre for Basic Literature, p. 328.
18. Melnyk, A. (2009). National and supranational institutions in the social world: dialectic of interconnection. *Bulletin of the Ternopil National Economic University*, *5*, pp. 33-39.
19. Mescon M.H., Michael, A., Khedouri, F.(1988). *Management*. Harper & Row, p. 777.
20. Mockler, R.J. (1971). Situational Theory of Management. *Harvard Business Review, 49*, *3*, pp. 146-155.
21. Nebeker, D. (1975). Situational Favourability and Perceived Environmental Uncertainty: An Integrative Approach. *Administrative Science Quarterly, 20(2)*, pp. 281-94, doi:10.2307/2391700.
22. Niehaus, M., Mocan, M., Hansen, K. (2024). Lecture Notes in Management and Industrial Engineering. Chapter, 3-14. In: G.I. Prostean, J.J. Lavios, L. Brancu, F. Sahin (Eds.), *VUCA and Its Impact on Business Organizations. Management, Innovation and Entrepreneurship in Challenging Global Times*. Springer. Retrieved from: https://doi.org/10.1007/978-3-031-47164-3_1.
23. Oliinyk, A.O., Zaiko, T.A., Subbotin, S.A. (2014). Factor analysis of transaction data bases. *Automatic Control and Computer Sciences*, *2*, pp. 34-47.
24. Polyanska, A., Babenko, V. (2012). Functioning of the mechanism of economic security management of industrial enterprises in the conditions of modern development. *Financial and credit activity-problems of theory and practice*, *2*, *13*, pp. 162-168.
25. Polyanska, A., Malynka, O. (2014). Knowledge management as basis of modern development of the companies. *Journal of Eastern European and Central Asian*, *1(2)*. Retrieved from: https://doi.org/10.15549/jeecar.v1i2.19.
26. Polyanska, A., Psiuk, R. (2019) Cognitive Methods of Manager Behaviour Formation in the Conditions of International Enterprise Activities. In: A. Hamrol, M. Grabowska, D. Maletic, R. Woll (Eds.), *Advances in Manufacturing II. Lecture Notes in Mechanical Engineering.* Cham: Springer, pp. 194-206.
27. Polyanska, A., Savchuk, S., Zapukhliak, I., Zaiachuk, Y., Stankovska, I. (2022). Digital Maturity of the Enterprise as an Assessment of its Ability to Function in Industry 4.0. *Advances in Manufacturing, III*, pp. 209-227. Retrieved from: https://doi.org/10.1007/978-3-030-99310-8_17
28. Polyanska, A., Pazynich, Yu., Mykhailyshyn, Kh., Buketov, V. (2023). Energy transition:

the future of energy on the base of smart specialization. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*. *No. 4,* pp. 89-95. Retrieved from: https://doi.org/10.33271/nvngu/2023-4/089.

29. Psyuk, V., Polyanska, A. (2024). The usage of artificial intelligence in the activities of mining enterprises. *E3S Web of Conferences*, *526, 01016*.
30. Savchuk, V. (2005). *Practical encyclopaedia. Financial management*. Kyiv: Maksymum. p. 884.
31. Sense, A. (2007). Knowledge Management and Situational Context. In: *Cultivating Learning within Projects*. London: Palgrave Macmillan. Retrieved from: https://doi.org/10.1057/9780230591967_6
32. Staehle, W.H. (1976). Situational Approach to Management. *Management International Review*, *16, 3*, pp. 59-69. Retrieved from: https://www.jstor.org/stable/40227278.
33. Thompson, A.A., Strickland, A.J. (2006). *Strategic management*. Williams Publishing House, p. 928.
34. Vladyko, O., Maltsev, D., Sala, D., Cichoń, D., Buketov, V., Dychkovskyi, R. (2022b). Simulation of leaching processes of polymetallic ores using the similarity theorem. *Rudarsko-Geološko-Naftni Zbornik*, *37(5)*, pp. 169-180. Retrieved from: https://doi.org/10.17794/rgn.2022.5.14.
35. Walsh, C. (2006). *Key management ratios*. K: Companion Group, p. 400.
36. Woodward, J. (1965). *Industrial organization: Theory and Practice*. Oxford, p. 281.
37. Zgurovskyi, M.Z., Pakhomov, Yu.M., Filipenko, A.S. (2010). *Geoeconomic development scenarios and Ukraine: monograph*. PC Akademiya, p. 328.

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GLOBAL EXHIBITION DAY AS A TOOL FOR BUILDING STAKEHOLDER EXPERIENCE IN THE EXHIBITION SECTOR

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Purpose: Conduct a case study of Global Exhibition Day (GED) as an event to build and share experiences of the exhibition sector worldwide.
Design/methodology/approach: 1) A literature review on building stakeholder experience in the exhibition sector. 2) Presenting the genesis and development of Global Exhibition Day. 3) Analysis of the specificity of the GED and its impact on building stakeholder experience in the exhibition sector (case study).
Findings: Global Exhibition Day (GED) has grown strongly since its inception. Every year, more and more trade fair organisers, exhibitors, service providers working for the industry and their organisations get involved in the initiative. In 2024, the day was celebrated in more than 100 countries and supported by more than 70 (in 2016 - around 30) trade fair organisations worldwide. The entire initiative has been coordinated from the beginning and documented on public social media by The Global Association of the Exhibition Industry (UFI), giving additional promotional resonance and inspiring further action for the rest of the exhibition industry. All the activities surrounding the GED build the experience of exhibition industry stakeholders and help to popularise it.
Research limitations/implications: The main limitation of the case study is the lack of opinion surveys of direct participants in the events to assess how the event is perceived by its participants. A quantitative study of GED participants will be a valuable development of this paper, which will indicate how to improve the delivery of the events that make up the GED.
Practical implications: The large number of events makes a comprehensive compilation of information about them hard to analyse. It would be good to group events not only by continent, such as 2024 but also by their specifics, target audience and objectives.
Social implications: Supporting the exhibition industry in seeking, selecting, assessing and learning about the trade shows development will ultimately result in an improved exhibiting sector.
Originality/value: Research on the trade fair industry is most often focused on its representatives' individual trade fair and exhibition activities dedicated to specific tag events. This work shows that their marketing activity is focused on popularising the industry as a whole. The paper shows that the GED is a simultaneous example of the cooperation and co-opetition of trade fair industry representatives that accompanies each participant's trade fair activity.
Keywords: stakeholder experience, trade shows, trade fairs, global exhibition day.
Category of the paper: case study and general review.

1. Introduction

Trade fairs, like the entire meetings industry (MICE sector), are evolving strongly (Alberca et al., 2018; Sarmento, Simões, 2019). The COVID-19 pandemic caused a number of restrictions on the development of the trade fair sector, including the temporary complete closure of the trade fairs. As a result, the situation for operators, operating in this sector, has radically changed. In most cases, trade fair organisers not only faced a drop in revenue but also had great difficulty maintaining financial liquidity (Vitali et al., 2022). The new beginning and the accompanying technological advances made the changes apparent. But even before the pandemic, the exhibition industry constantly looked for its way forward. One idea was to integrate the sector through a cyclical celebration of the entire industry, the Global Exhibition Day (GED). An initiative by the Polish Chamber of Exhibition Industry in 2014 resulted in the establishment of Global Exhibition Day, celebrated every first Wednesday in June since 2016.

This paper aims to conduct a case study of Global Exhibition Day and showcase it as an event to build and share the experiences of the exhibition sector worldwide. The growth of the exhibition industry requires an increasing investment in the exhibition infrastructure on which base trade fairs are organised (Vitali et al., 2022). Infrastructure development must consider the future expectations of trade fair participants (Celuch, 2021). The global exchange of experiences of the exhibition sector helps to diagnose the expectations of participants, anticipate the directions of the sector's development, and thus better plan exhibition investments (Alberca et al., 2018). Analysing the development process of Global Exhibition Day will allow one to see which activities are most popular and which do not live up to expectations.

The paper uses reports of the International Trade Fair Organisation and national organisations coordinating the exhibition industry in individual countries (including the Polish Chamber of Exhibition Industry), documenting the preparation and implementation of the event, as well as the pace of its development and results. The initiators of the GED idea emphasised that it was not a single event. They described it as an invitation to increase involvement in promoting the exhibition industry and its initiatives. The case study was preceded by a traditional literature review on building stakeholder experience.

2. Building stakeholder experience in the exhibition sector – literature review

Experience encompasses the totality of thoughts, emotions, sensations, perceptions and interactions that define human identity (Lemke et al., 2011). Experience is inherently multifaceted and deeply subjective. Even identical events can be perceived differently by

different people, influenced by their culture, values, past experiences and context (De Keyser et al., 2020). Experiences are built when interacting with the market and its other participants (Prymon-Ryś, 2023; Gustafsson et al., 2024). A trade fair is a space where those involved in shaping a particular industry meet. Therefore, their contacts and relationships result in experiences that are important for the development of these companies.

Traditionally, exhibitors and visitors have been cited as the main stakeholder groups (Wreder et al., 2009; Lin et al., 2016) at trade fairs and are the most visible at these events (Zmyslony, Borodako, 2017). Trade fairs are a popular communication tool (Tafesse, Skallerud, 2017; Sarmento, Simões, 2018). Their participants often decide intuitively and without deeper analysis to participate in them because they find them helpful in achieving many business objectives (Kennelly, 2017). However, when analysing the functioning of the fairs, one can observe an increasing integration of these events with the region, its inhabitants and the companies operating in their surroundings (Adamczyk, Gębarowski, 2008; Sarmento, Simões, Cláudia Farhangmehr, 2015). Local governments are increasingly aware of the impact of organising such events on the development of the region and therefore strongly support them (Kowalik, 2012). At the same time, local entrepreneurs seek to take advantage of the event held in the region to present themselves, offer their services directly at the fair, and establish contacts for future cooperation. (Gruenberg, 2014). To support these objectives, the organisers seek to implement additional events to accompany the main fair event (Gopalakrishna et al., 2017). These events are designed to increase participant involvement and attendance, increasing media interest (Crowther, 2011). In this way, first and foremost, relationships were built with stakeholders, and there was an additional exchange of knowledge and experience (Çevik, Şimşek, 2020). Extensive photographic and film documentation makes it possible to prepare media publications by exhibitors, visitors, and media representatives (Gillooly et al., 2017). Analyzing the published content is an additional source of information and experience for former participants and those who did not participate directly in the fair (Wong, Lai, 2018).

However, multiplying the experience so that each successive one adds value for the participants is not straightforward (Derakhshan, Turner, 2022; Calza et al., 2023). It requires a broad understanding of the expectations of all stakeholders and the objectives behind their presence at the fair (Lin et al., 2015). In addition, the expansion of the offer for trade fair participants increases the problems of coordinating the preparations for the fair and optimising the schedule. The necessity to prepare the trade fair event much in advance, the limitations of its modification, and the difficulties in finding out precisely which visitors will show up at the trade fair make it impossible to adapt to all expectations fully (Lin, 2016). It is helpful in the quest to increase the satisfaction of trade fair participants by specifying what they can expect at the event. Such information will help them decide whether to attend the event and how to plan their time during the fair. One of the critical elements of building relationships with stakeholders is precise information about the nature of the event and its accompanying events. The 'event personality' appears in the literature as an element influencing exhibitor happiness

(Rai, Nayak, 2018). Defining an 'event personality' really helps position the event and attract the attention of those who might be interested in it.

Integral to the development of trade fair events is the assessment of their usefulness to participants (Hansen, 2004). One tool is the analysis of the trade fair experience of exhibitors and visitors. The main experience dimensions that are investigated are happiness and satisfaction (affective aspects), economic effect and contemporary learning (cognitive aspects), physical comfort (physical elements), uniqueness (unique dimension) and overall satisfaction (well-being dimension). The event experience scales proposed in the literature define different dimensions for evaluating experiences. The following works refer to the cognitive, affective and physical aspects of experiences (Mannell, Iso-Ahola, 1987; Getz, 2007). Unique and well-being dimensions appear in (Rinallo et al., 2010). Physical aspects are analysed in (Gopalakrishna et al., 2010; Tafesse et al., 2010; Sarmento, Simões, 2018) write about the leisure aspects of individuals. The most extensive proposal is a five-dimensional event experience scale consisting of cognitive, affective, physical, unique, and well-being dimensions (Rai, Nayak, 2020)

Subsequent studies have increasingly clearly shown that the experience of trade fair participants is multidimensional and highly influences participants' future trade fair decisions. Hence, there is a constant need to analyse the trade fair experience and look for opportunities to enrich it.

3. Global Exhibition Day – causes and circumstances of the origin

In 2014, the Polish Chamber of Exhibition Industry took the initiative to establish a Global Exhibition Day. The first proposal for the date of this event was the fifteenth of April. The rationale behind this proposal was when the Global Association of the Exhibition Industry was established (UFI; 15.04.1925). The assumption was that such an event would help to raise awareness among entrepreneurs of the role of trade fairs in business marketing and their importance for economic development. In addition, a joint initiative of trade fair organisers should help them to unite and exchange experiences. Subsequent discussions meant that the final formula for the day brought together Paris-based UFI - The Global Association of the Exhibition Industry, and Dallas-based IAEE - The International Association of Exhibitions and Events, who began joint preparations for the day.

Finally, Global Exhibition Day was established in 2016 and is celebrated every year on the first Wednesday of June (only the celebration of the first edition of GED was exceptionally held on 8.VI.2016). Practical preparations for implementing the first edition of this day started in Europe on the fifth of January 2016, when the Operational Group of the Global Exhibitions Day campaign was established. On the eighth of April 2016, during the General Assembly of

CENTREX in Poznań, at the Poznań International Fair, the promotional campaign for the event was approved. In May 2016, the online campaign "Global Exhibitions Day 2016" was launched. The coordinator of the European part of the campaign was the Polish Chamber of Exhibition Industry. The Polish National Chamber of Commerce patronised the Global Exhibitions Day 2016 campaign.

The event has its website (https://ged.eventmaker.io/en; 10.07.2024), where you can see the status of the current edition of the event and archives from previous years. On Facebook, one can find the Global Exhibitions Day public group (https://www.facebook.com/groups/GlobalExhibitionsDay; 10.07.2024), which has 3600 members. On LinkedIn, the slogan 'Celebrate Global Exhibitions Day with me' has become very popular, and it is also accompanied by 'I'm celebrating Global Exhibitions Day! Join me". And exhibition industry representatives greeted each other with the slogan "Happy Global Exhibitions Day!". Since the beginning of Global Exhibition Day, the hashtag #GED supplemented by the year the event takes place (e.g. #GED2024), has been used in subsequent years. This hashtag marks all events surrounding the day's celebration on social media. In addition, each year, the UFI prepares and makes the day's logo and complementary infographics highlighting the relevance of the exhibition industry globally and regionally available to interested parties. These materials help to unify the visual identity of the day and make it easier to recognise the associated events.

Today, you can get involved in celebrating the GED by:

- downloading the #GED2024 Toolkit,
- adding own GED Activity to the global map,
- claiming their tree in the GED Forests.

An exciting feature is the interactive world map showing where the events supporting the GED occur (https://ged.eventmaker.io/en/join-global-activities; 10.07.2024). You can see how the event has developed over the years. On the one hand, this map shows the scale of the event and on the other hand, it is very inspiring for others looking for a way to celebrate the GED. The Toolkit (https://ged.eventmaker.io/en/toolkit; 10.07.2024) on the Global Exhibitions Day website is very helpful for GED organisers in various regions. There, you can find poster designs advertising the current GED, posters, presentations and infographics with information about the fair prepared for the different areas of the world.

The first edition of the GED has already succeeded in uniting more than 30 trade fair industry coordination organisations worldwide, and the hashtag #GED2016 has become very popular on social media. Also, thanks to the mass distribution of manuals to industry employees explaining how to promote the GED on social media.

In the following years, further editions of the day were implemented. Each successive one was increasingly popular and spawned the involvement of new participants. A difficult time was the pandemic, when the organisation of offline events (including fairs) was periodically suspended. Despite this, the GED celebrations were hectic on social media, and many organisations shared information about their initiatives to celebrate the GED.

In 2023, Global Exhibitions Day activities carried out in the run-up to and during the day were accompanied by more than 3000 unique pieces of content (in the form of posts, comments and messages). Thousands of people worldwide used the hashtag #GED2023 to show their bond with the exhibition industry (https://www.ufi.org/wp-content/uploads/2023/06/8th-GED-Celebrated-Worldwide.pdf; 10.07.2024). The event has grown so much that in 2024 this event was celebrated in more than 100 countries and regions worldwide.

4. Building stakeholder experience with Global Exhibition Day – case study

The themes and key areas of interest, which are defined for each edition of the GED, help to consciously shape the image of the day and use it to promote the trade fair industry. Each time, a different element of the trade fair reality is emphasised, but the authors always stress the role and importance of the trade fair industry for companies and the economy (Table 1).

Table 1.
The themes of Global Exhibition Days (#GED2024)

Year	Date of the GED	Themes/Key Areas of Interest
2016	08.06.2016	The Dynamics of Transition – Our Industry's Complex Future
2017	07.06.2017	Think Global – Act Local (the people and jobs in the exhibition industry)
2018	06.06.2018	Advocate industry issues with politicians and stakeholders, and finding new ways to connect with young people to attract the right talent to the exhibition industry
2019	05.06.2019	The global economic impact of trade fairs and their contribution to the protection of resources
2020	03.06.2020	Making The Invisible Giant Visible (exhibitions are keys to rebuilding economies)
2021	02.06.2021	Exhibitions are the fastest of fast tracks to economic recovery Exhibitions are the key instrument to implement and accelerate transformation towards sustainable and digital economies!
2022	01.06.2022	We Draw the New World Together
2023	07.06.2023	We Run The Meeting Places And Marketplaces For Everyone
2024	05.06.2024	Exhibitions Are Catalysts To Sustainable Futures

Source: own compilation based on UFI materials.

In subsequent years, the main slogans (Table 1) are supplemented with detailed information about the functioning of economic fairs and their role in the economy. For example, in 2024, the main slogan is also augmented by four complementary messages, which show that economic fairs are a source of progress and economic development. In addition, they bring people together and provide an opportunity for sustainable implementation.

UFI and IAEE coordinate Global Exhibition Day, but any member of the trade fair community can initiate individual events worldwide. Workshops and conferences on the role of trade fairs in the economy are organised to celebrate the GED. Regional trade fair organisations prepare competitions and presentations. They invite their exhibitors, visitors,

and representatives of local authorities and business organisations to celebrate together. These initiatives provide a basis for discussing the future of the trade fair sector and exchanging experiences in trade fair management. To make the discussion engaging for the broadest possible community, the workshops organised during the GED include topics on sustainability and climate concerns. The trade fair industry strives to develop solutions to help rationalise using materials to construct trade fair presentations.

The 2024 GED was supported by over 70 national and international exhibition industry associations. Some activities boiled down to a collaborative photograph accompanied by a hashtag. However, others included infographics summarising regional trade fair activity, reports, academic papers and multi-day conferences. (https://www.ufi.org/wp-content/uploads/2024/06/9th-GED-Celebrated-Worldwide_Media-Release.pdf; 10.07.2024).

Social media activity included deep interactions between individual celebrants, and UFI and regional activity coordinators gave thanks for the commitment of individual partners. The unwavering scale of the Global Exhibitions Day celebrations and the high level of interest from businesses and media show that the GED can be considered a hit initiative. After the pandemic, there has been a growing interest in organising and participating in trade fairs, and the GED certainly has a part to play in this. At the same time, it should be noted that the trade fair industry is getting increasingly creative in developing its activities. In addition to the GED, further initiatives are emerging to ensure that more and more people learn about and discuss the importance of trade fairs throughout the year.

Such activities include, for example, the permanent campaign of the Polish Chamber of Exhibition Industry (PCEI) under the slogan "Trade fairs give more" (https://targidajawiecej.pl/; 10.07.2024). Its activity centres around a blog with the same title, where one can learn much about the exhibition industry. It is a place for the publication of reports on the situation of the exhibition industry in the following years, initiatives of individual exhibition centres in Poland and international cooperation in the exhibition area. The constant contact of the exhibition community with this information is very inspiring for those looking for opportunities to intensify their marketing activities to popularise the exhibition industry in Poland. Another activity of PCEI is the Young at the Fair Club (https://polfair.pl/klub-mlodzinatargach-przy-polskiej-izbie-przemyslu-targowego/; 10.07.2024), an organisation established at the Polish Chamber of Exhibition Industry which brings together young people interested in fairs. Young people learn practically about the possibilities of the trade fair industry and become its natural ambassadors.

Individual trade fair organisations survey attitudes and expectations towards the trade fair industry in cooperation with research agencies to better prepare for the next GED and ongoing marketing activity. One such study is summarised in a report prepared by the Infuture.institute (infuture.institute, 2022), which shows that:

- One of the most important needs visitors and exhibitors meet at trade fairs is networking and nurturing relationships with others. Trade fair participants expect additional activities designed for specific groups of exhibitors or visitors. They want to have an active influence on their form so that they are fully responsive to their needs (themed groups in social media)
- Trade fair participants expect the organisers to take care of not only their business needs related to their role as exhibitors and visitors but also their well-being during their stay at the fair. And it is not only about toilets and restaurants but also about quiet areas, children's playgrounds, etc.
- Trade fairs should not only play a city-building role but should be organised like cities, where every space is dedicated to achieving marketing objectives.
- The trade fair industry (as well as MICE) should implement elements of modern technology in a functional way to meet the need for multi-sensoriality, building relationships and creating more engaging experiences.
- An essential element is the pursuit of self-sufficiency in energy (Lewicka et al., 2023, p. 7), water and digital fair facilities (in line with the 17 Sustainable Development Goals of the Directive Agenda2030; https://sdgs.un.org/2030agenda; 10.07.2024).
- Humanity's most significant challenge today is managing change and flexibly adapting to a changing environment. The ability to react quickly should also be subordinated to a long-term perspective, allowing to build resilience and prepare for future challenges.

The nature of Global Exhibitions Day and its accompanying events fits perfectly with the forecasts defined in the presented report and helps meet the expectations listed for the exhibition industry. It can be assumed that it is a needed component of the promotion and development of the sector.

5. Conclusions

Building relationships with others is today's exhibitors and visitors' most strongly articulated goal of participation (Proszowska, 2018; Karacaoğlu, Sert, 2019). Therefore, trade show organizers must search for opportunities to create spaces for these activities (Huang, 2016). Individually developed solutions will be improved when they draw on the experience of other organizers and are made based on surveys of their stakeholders.

Global Exhibitions Day is an initiative that strongly activates the exhibition community and shows entrepreneurs trade fairs as an essential instrument for shaping business reality. GED is a marketing activity of the exhibition industry focused on the post-pollination of the entire industry. Inaugurated in 2016, the initiative has been growing very well, even though in

the meantime the industry went through a challenging experience, which was the COVID-19 pandemic.

Each year, more people and institutions join the celebration of Global Exhibitions Day and more events are organized. All these activities are accompanied by very professional and intensive social media activities. It is precious that the initiators of the GED do not stop at creating an atmosphere of celebration of the industry but use the events accompanying the GED to survey the expectations of the entire exhibition industry. The GED is an example of the cooperation and coopetition of trade show industry representatives accompanying each participant's individual trade show activity.

Based on the analysis of the case study conducted on the mentioned event, it can be forecasted that the trade fair industry will develop in a sustainable manner and meet the future challenges of the business reality surrounding it.

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References

1. Adamczyk, J., Gębarowski, M. (2008). Targi a rozwój miasta i regionu (na przykładzie Rzeszowa oraz województwa podkarpackiego). *Studia i Prace Kolegium Zarządzania i Finansów, Vol. 87*, pp. 24-36.
2. Alberca, P., Parte, L., Rodríguez, A. (2018). The metaefficiency of trade shows: a benchmarking analysis by sector. *Benchmarking, Vol. 25, Iss. 8*, pp. 2875-2891. Retrieved from: https://doi.org/10.1108/BIJ-06-2017-0129.
3. Calza, F., Sorrentino, A., Tutore, I. (2023). Combining corporate environmental sustainability and customer experience management to build an integrated model for decision-making. *Management Decision, Vol. 61, Iss. 13,* pp. 54-84. Retrieved from: https://doi.org/10.1108/MD-05-2022-0613.
4. Celuch, K. (2021). Event technology for potential sustainable practices: a bibliometric review and research agenda. *International Journal of Event and Festival Management, Vol. 12, Iss. 3*, pp. 314-330. Retrieved from: https://doi.org/10.1108/IJEFM-08-2020-0051.

5. Çevik, H., Şimşek, K.Y. (2020). The effect of event experience quality on the satisfaction and behavioral intentions of motocross World Championship spectators. *International Journal of Sports Marketing and Sponsorship, Vol. 21, Iss. 2*, pp. 389-408. Retrieved from: https://doi.org/10.1108/IJSMS-05-2019-0052.
6. Crowther, P. (2011). Marketing event outcomes: From tactical to strategic. *International Journal of Event and Festival Management, Vol. 2, Iss. 1*, pp. 68-82. Retrieved from: https://doi.org/10.1108/17582951111116623.
7. De Keyser, A., Verleye, K., Lemon, K.N., Keiningham, T.L., Klaus, P. (2020). Moving the customer experience field forward: introducing the touchpoints, context, qualities (TCQ) nomenclature. *Journal of Service Research, Vol. 23, Iss. 4,* pp. 433-455. Retrieved from: https://doi.org/10.1177/1094670520928390.
8. Derakhshan, R., Turner, R. (2022). Understanding stakeholder experience through the stakeholder journey. *Project Leadership and Society, Vol. 3(September)*, p. 100063. Retrieved from: https://doi.org/10.1016/j.plas.2022.100063.
9. Getz, D. (2007). *Event Studies: Theory, Research and Policy for Planned Events*. Abingdon: Elsevier.
10. Gillooly, L., Crowther, P., Medway, D. (2017). Experiential sponsorship activation at a sports mega-event: The case of cisco at London 2012. *Sport, Business and Management: An International Journal, Vol. 7, Iss. 4,* pp. 404-425. Retrieved from: https://doi.org/10.1108/SBM-04-2016-0015.
11. Gopalakrishna, S., Malthouse, E.C., Lawrence, J.M. (2019). Managing customer engagement at trade shows. *Industrial Marketing Management, Vol. 81, Iss. 3*, pp. 99-114. Retrieved from: https://doi.org/10.1016/j.indmarman.2017.11.015.
12. Gopalakrishna, S., Roster, C.A., Sridhar, S. (2010). An exploratory study of attendee activities at a business trade show. *Journal of Business & Industrial Marketing, Vol. 25, Iss. 4*, pp. 241-248. Retrieved from: https://doi.org/10.1108/08858621011038199.
13. Gruenberg, M.L. (2014). Making the Most of Trade Shows. *Online Searcher, Vol. 38, Iss. 1/2*, pp. 58-61.
14. Gustafsson, A., Caruelle, D., Bowen, D.E. (2024). Customer experience (CX), employee experience (EX) and human experience (HX): introductions, interactions and interdisciplinary implications. *Journal of Service Management, Vol. 35, Iss. 3*, pp. 333-356. Retrieved from: https://doi.org/10.1108/JOSM-02-2024-0072.
15. Hansen, K. (2004). Measuring performance at trade shows: Scale development and validation. *Journal of Business Research, Vol. 57, Iss. 1*, pp. 1-13.
16. Huang, H.C. (2016). How Does Meetings, Incentives, Conventions, and Exhibitions Industry Attract Exhibitors? *Asia Pacific Journal of Tourism Research, Vol. 21, Iss. 1*, pp. 73-93. Retrieved from: https://doi.org/10.1080/10941665.2015.1016444.
17. https://ged.eventmaker.io/en
18. https://ged.eventmaker.io/en/join-global-activities

19. https://polfair.pl/klub-mlodzinatargach-przy-polskiej-izbie-przemyslu-targowego/
20. https://sdgs.un.org/2030agenda
21. https://targidajawiecej.pl/
22. https://www.facebook.com/groups/GlobalExhibitionsDay
23. https://www.linkedin.com/pulse/celebration-global-exhibitions-day-2016-mark-zu-feng-ye/
24. https://www.ufi.org/wp-content/uploads/2023/06/8th-GED-Celebrated-Worldwide.pdf
25. https://www.ufi.org/wp-content/uploads/2024/06/9th-GED-Celebrated-Worldwide_Media-Release.pdf
26. infuture.institute (2022). *W kierunku rezyliencji. Przyszłość branży targowej.*
27. Karacaoğlu, S., Sert, A.N. (2019). An Evaluation for Participation Motivations of Professional and Non-Professional Visitors: The Case of Travel Turkey İzmir Fair. *Journal of Yasar University, Vol. 14, Iss. 55*, pp. 329-338.
28. Kennelly, M. (2017). "We've never measured it, but it brings in a lot of business": Participatory sport events and tourism. *International Journal of Contemporary Hospitality Management, Vol. 29, Iss. 3*, pp. 883-899. Retrieved from: https://doi.org/10.1108/IJCHM-10-2015-0541.
29. Kowalik, I. (2012). Influence of trade fairs on a host city brand. *Public Policy and Administration Vol. 11, Iss. 4*, pp. 629-640.
30. Lemke, F., Clark, M., Wilson, H. (2011). Customer experience quality: an exploration in business and consumer contexts using repertory grid technique. *Journal of the Academy of Marketing Science, Vol. 39, No. 6*, pp. 846-869, doi: 10.1007/s11747-010-0219-0.
31. Lewicka, D., Zarebska, J., Batko, R., Tarczydło, B., Woźniak, M., Cichoń, D., Pec, M. (2023). *Circular Economy in the European Union: Organisational Practice and Future Directions in Germany, Poland and Spain*. London/New York: Routledge. Retrieved from: https://doi.org/10.4324/9781003411239.
32. Lin, Y. (2016). An examination of determinants of trade show exhibitors' behavioral intention. *International Journal of Contemporary Hospitality Management, Vol. 28, Iss. 12*, pp. 2630-2653. Retrieved from: https://doi.org/10.1108/IJCHM-06-2015-0318.
33. Lin, Y.K., Kerstetter, D., Hickerson, B. (2016). Constructing a trade show exhibitor satisfaction scale from a stakeholder perspective. *Journal of Tourismology, Vol. 2, Iss. 2*, pp. 13-35.
34. Lin, Y., Kerstetter, D., Hickerson, B. (2015). *Developing a Trade Show Exhibitor's Overall Satisfaction Measurement Scale. Tourism Travel and Research Association: Advancing Tourism Research Globally*. Retrieved from: http://scholarworks.umass.edu/ttra/ttra2015/Academic_Papers_Oral/28%0AThis, 15.07.2024.
35. Mannell, R.C., Iso-Ahola, S.E. (1987). Psychological nature of leisure and tourism experience. *Annals of Tourism Research, Vol. 14, Iss. 3*, pp. 314-331.

36. Proszowska, A. (2018). Evaluation Methods Of Trade Fairs Results Employed By Exhibitors – Overview And Scope Of Application. *Handel Wewnętrzny, Vol. 5, Iss. 376*, pp. 236-246.
37. Prymon-Ryś, E. (2023). Implementation and evaluation of a selected CRM tool for the stakeholder relationship management in an innovative project. *Marketing of Scientific and Research Organisations, Vol. 49, Iss. 3*, pp. 123-140.
38. Rai, S., Nayak, J.K. (2018). Role of event personality and exhibitors' eudaimonic and hedonic happiness in predicting event advocacy intentions: An empirical study. *International Journal of Event and Festival Management, Vol. 9, Iss. 1*, pp. 86-103. Retrieved from: https://doi.org/10.1108/IJEFM-09-2017-0056.
39. Rai, S., Nayak, J.K. (2020). Conceptualization and development of event experience scale: lessons from India. *Tourism Review, Vol. 75, Iss. 2*, pp. 369-381. Retrieved from: https://doi.org/10.1108/TR-10-2018-0143.
40. Rinallo, D., Borghini, S., Golfetto, F. (2010). Exploring visitor experiences at trade shows. *Journal of Business & Industrial Marketing, Vol. 25, Iss. 4*, pp. 249-258. Retrieved from: https://doi.org/10.1108/08858621011038207.
41. Sarmento, M., Simões, Cláudia Farhangmehr, M. (2015). Applying a relationship marketing perspective to B2B trade fairs: the role of socialization episodes. *Industrial Marketing Management, Vol. 44, Iss. 1*, pp. 131-141.
42. Sarmento, M., Simões, C. (2018). The evolving role of trade fairs in business: A systematic literature review and a research agenda. *Industrial Marketing Management, Vol. 73, Iss. 5*, pp. 154-170.
43. Sarmento, M., Simões, C. (2019). Trade fairs as engagement platforms: the interplay between physical and virtual touch points. *European Journal of Marketing, Vol. 53, Iss. 9*, pp. 1782-1807. Retrieved from: https://doi.org/10.1108/EJM-10-2017-0791.
44. Tafesse, W., Korneliussen, T., Skallerud, S.K. (2010). Importance performance analysis as a trade show performance evaluation and benchmarking tool. *Journal of Convention and Event Tourism, Vol. 11, Iss. 4*, pp. 314-328.
45. Tafesse, W., Skallerud, K. (2017). A systematic review of the trade show marketing literature: 1980-2014. *Industrial Marketing Management, Vol. 63*, pp. 18-30.
46. Vitali, V., Bazzani, C., Gimigliano, A., Cristani, M., Begalli, D., Menegaz, G. (2022). Trade show visitors and key technological trends: from a literature review to a conceptual framework. *Journal of Business and Industrial Marketing, Vol. 37, Iss. 13*, pp. 142-166. Retrieved from: https://doi.org/10.1108/JBIM-10-2021-0461.
47. Wong, J.W. C., Lai, I.K.W. (2018). Evaluating Value Co-creation Activities in Exhibitions: An Impact-Asymmetry Analysis. *International Journal of Hospitality Management, Vol. 72,* pp. 118-131. Retrieved from: https://doi.org/DOI: 10.1016/j.ijhm.2018.01.011.

48. Wreder, A., Johansson, P., Garvare, R. (2009). Towards a stakeholder methodology: Experiences from public eldercare. *TQM Journal, Vol. 21, Iss. 2,* pp. 194-202. Retrieved from: https://doi.org/10.1108/17542730910938173.
49. Zmyslony, P., Borodako, K. (2017). Exhibition industry in Poland-current status and trends. *KNUV, Vol. 4, Iss. 54*, pp. 209-221.

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LINKING ECOLOGICAL FOOTPRINT WITH ECONOMIC GROWTH. EVIDENCE FROM CENTRAL EUROEPAN COUNTRIES

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Purpose: The aim of this paper is to examine the relationship between economic growth and ecological footprint in Central European countries in the years 1990-2022.
Design/methodology/approach: In order to examine the relationship between economic growth and ecological footprint, the following tools were used: literature analysis, analysis of the dynamics of the variables, descriptive statistics, Pearson correlation coefficient, and graphical construction of the environmental Kuznets curve.
Findings: The analysis of the relationship between economic growth and ecological footprint in Central European countries indicated its diversification both over time and between the analyzed countries. Analysis of values calculated using descriptive statistics showed diversification of the results obtained for selected countries and variables. The use of Pearson correlation coefficient provided a basis for confirming the existence of a relationship between economic growth and economic footprint. The obtained results also confirm the presence of a non-linear relationship between economic growth and ecological footprint and the possibility of describing it using EKC, which for the Slovak Republic and the Czechia takes the shape of an inverted-U, while for Hungary and Poland the EKC curve was N-shaped.
Practical implications: This paper promotes the problem of economic growth. They can assist in the development of policies and practices that both support economic growth and reduce its negative environmental impact.
Social implications: The subject of the article concerns economic growth, which contributes to improving the quality of life of societies.
Originality/value: The article analyzes using the most current statistical data of selected variables and statistical tools.
Keywords: economic growth, ecological footprint, environmental Kuznets curve.
Category of the paper: Research paper.

1. Introduction

Economic growth is the basis for the efficient functioning of the economy and satisfying human needs. The concept of economic growth refers to quantitative changes in the economy that are a consequence of the constant increase in economic capacity, both of a material and human nature (Harrod,1973; Lewis, 1963; Kuznets,1971; Rostow, 1953; Solow, 2000; Barro, Sala-i-Martin, 2004; Romer, 2005; Woźniak, 2004). In the definition of economic growth referred to, it can be seen that natural, human and capital resources are required to ensure the economic well-being of society. The pursuit of ever-increasing prosperity therefore contributes to an increased demand for these resources. But also, the resources determine the volume of production in the economy and thus the level of satisfaction of societies. Over the last 200 years, the main focus of economics has been on maximizing profits and production, which was associated with a continuous increase in the exploitation of available resources (Rogall, 2010). However, starting from the 1970s, the emergence of studies focusing on the problem of natural resources consumption can be noticed. One can be mentioned: neoclassical environmental economics, ecological economics, new ecological economics, or the concept of sustainable development (Rogall, 2010). Emerging research points to the importance of measuring resource exploitation, along with the need to use them efficiently in the production of goods. The 21st century poses challenges to economies such as increasing demand for natural resources in order to achieve economic growth. Until recently, carbon dioxide emissions (along with sulfur dioxide and nitrogen oxide emissions) were the main measure of environmental degradation because of the production (Babu, Datta, 2013). However, these only measure the effects on air, which represents just one facet of pollution and thus they ignore other important dimensions of environmental impacts (Al-Mulali et al., 2015; Jha, Murthy, 2003). An increasing number of papers point to the importance of measuring the state of the environment through the analysis of the ecological footprint, which provides a better understanding than CO_2 emissions (Aydin et al., 2019; Destek, Sarkodie, 2019; Wang, Dong, 2019; Ozturk, Acaravci, 2013; Saud et al., 2018; Yin et al., 2019). The ecological footprint measures the demand for the natural resources of the biosphere in hectares of land and sea surface that are used for consumption and waste absorption (Kłos, 2014; Wackernagel, Kitzes, 2008). This demand translates into the demand for six main types of land – cropland, grazing land, fishing grounds, forest product, built-up land and carbon (Borucke et al., 2013; Wackernagel, Rees, 1996). The first four of these land types produce food, fiber and wood products for direct or indirect human consumption. The fifth type of land, built-up land, represents the area required for physical infrastructure such as cities and roads. The sixth type of land is carbon, representing the amount of biologically productive space required to absorb one of the most important waste products of the human economy: carbon dioxide (CO_2). The analysis of global data on the ecological footprint (https://data.footprintnetwork.org) leads

to the conclusion that in many countries value of ecological footprint exceeds the production capacity of their economies. The question therefore arises whether and to what extent the state of the state of the environment is correlated with the level of economic growth. In recent decades, many studies have been written examining this relationship. Their time range, subject, and methodological scope varies widely. Many of them are subject to developing and emerging countries. Most often, they are concerned about time periods up to the year 2015 and use carbon dioxide emissions as an indicator of the state of the environment degradation. Hence, to fill this gap, the aim of this paper is to examine the relationship between economic growth and ecological footprint in Central European countries between 1990 and 2022. The research statement posed in this way is reflected in the structure of the paper. The literature review presents the results of research conducted for the search for the relationship between economic growth and ecological footprint in the last decade. The next part presents the research method along with the data source. Then, an analysis is carried out and then a discussion of the obtained results regarding the relationship between economic growth and ecological footprint in Central European countries with those presented in the literature review.

2. Literature review

This section reviews existing research on the relationship between economic growth and environmental quality. Over the past three decades, many studies have investigated the relationship between these variables, including their determinants. The relationship between economic growth and environmental pollution was first introduced to the literature by (Grossman, Krueger, 1991) and first used by (Panayotou, 1993) and called the environmental Kuznets curve (EKC). The concept of the curve referred to the relationship between income inequality and economic development described by Kuznets in the mid-1950s (Kuznets, 1955) and assumed that the environmental Kuznets curve is most often inverted U-shaped. This means that at a low level of income, the intensity and degree of environmental degradation are low. Then, intensive agricultural development and industrialization cause the consumption of natural resources at a faster rate than their renewal. At a higher level of economic development, where ecological knowledge and awareness are used, government instruments and environmentally friendly technologies cause a gradual reduction in degradation. In many studies, the environmental Kuznets curve takes the form of the letter N. This means that the previously described improvement of the environment, following the crossing of the turning point, occurs only up to a certain level of economic development, after which environmental degradation increases again (Gruszecki, Jóźwik, 2019). Despite many doubts and criticism, the environmental Kuznets curve remained in the center of researchers' interest and was systematically developed in the following years (Genstwa, 2020). Initially, the main measure

of the state of environmental degradation was CO_2 emissions. The studies, analyzing relation between economic growth and CO_2 can be mentioned are as follow: Acaravci, Ozturk (2010), Al-Mulali et al. (2013), Dogan (2020), Osabuohien et al. (2014), Jammazi, Aloui (2015) (Chaabouni, Zghidi, Mbarek, Ben, 2016; Zaidi, Saidi (2018), Acheampong et al. (2023), Wang (2013), Osabuohien et al. (2014). The ecological footprint has emerged as a new indicator of environmental degradation and is currently considered as a more comprehensive indicator than CO_2 emissions. This literature review refers to studies that address the issue of the relationship between economic growth and ecological footprint. Table 1 contains a list of authors who have analyzed the relationship between these variables in the last decade. It can also be seen that most of the studies concern developing economies, mainly from Africa and Asia. Only a small number of papers refers to European countries or Central European countries. The diversity of the comparison also concerns the time period of variables. Only half of them analyzed variables collected for a period of more than 30 years. The rest concern shorter periods. Most studies confirm the existence of a relationship between economic growth and ecological footprint. The works supporting the EKC concept are as follow: Aşici, Acar (2016), Charfeddine, Mrabet (2017), Ulucak, Bilgili (2018), Bello et al. (2018), Destek et al. (2018), Altıntaş, Kassouri (2020), Ulucak, Khan (2020), Dardouri, Smida (2023), Alruweili (2023), Feng, Wu (2011). In most studies, the authors confirmed the inverted-U-shaped relationship between GDP and ecological footprint: Feng, Wu (2011), Nesrine et al. (2023), Destek et al. (2019), Mehmet et al. (2018), Mrabet et al. (2017). N-shaped ECK has been confirmed in works: Destek et al., 2018 and Dardouri, Smida (2023), Lazar et al. (1019). However, the EKC concept was not confirmed in the following works: Usman et al. (2020), Ozturk, Avaravci (2010). Among the large group of studies examining the relationship between economic growth and ecological footprint, there are also those analyzing European countries. The paper of Destek et al. (2018) referred to 15 Western European countries, in which the authors confirmed the existence of U-shaped EKC for data from 1980-2013. Alola et al. (2019) confirmed the relationship between gross domestic product and ecological footprint for 16 Western European countries for the period 1997-2014. Altintas et al. (2020) collected data from 14 European countries for the period 1990–2014, based on which they proved the existence of EKC sensitivity to environmental degradation. Lazăr et al. (2019) confirmed the nonlinear relationship between GDP and carbon dioxide emissions for the Central and Eastern European countries, confirming the N-shaped, inverted-N, U-shaped, inverted-U, monotonic, or no statistical link. In their study, they proved that Czechia and Hungary displayed traditional inverted-U-shaped EKC, and Poland and Slovak Republic inverted-N-shaped. Also, the authors as Raihan et al. (2024), Jamel et al. (2017), and Addai et al. (2023) confirmed the positive relationship between economic growth and carbon dioxide emissions. Such a relationship was also studied by Saud et al. (2019) for 18 Central and Eastern European countries for the period 1980-2016. Based on the analysis, they confirmed the existence of a relationship between these variables only for five countries: Croatia, Poland, Serbia, the Slovak Republic and Ukraine. To sum up the

literature analysis, it can be stated that most of the studies examining the relationship between economic growth and ecological footprint refer to developing countries. Only a small part of them concerns the description of the situation in European economies, especially in Central European countries. However, the vast majority of researchers confirmed the existence of a relationship, mainly non-linear, between these two variables.

Table 1.
Literature review on economic growth – ecological footprint relationship

Author	CHARACTERISTICS	
	time period	**region/country**
Feng, Wu (2011)	1996–2008	China
Al-Mulali and Ozturk (2015)	1996–2012	14 MENA countries
Aşıcı and Acar (2016)	2004–2008	116 countries: high, middle and low-income
Charfeddine andMrabet (2017)	1975–2007	15 MENA countries
Marbet et al. (2017)	1980-2011	Qatar
Uddin et al. (2017)	1991–2012	27 highest emitting countries
Bello et al. (2018)	1971–2016	Malaysia
Destek et al. (2018)	1980–2013	15 European Union countries
Ulucak and Bilgili (2018)	1961–2013	15 high-, 15 middle-and 15 low-income countries
Destek and Sarkodie (2019)	1977–2013	Newly industrialized countries South Korea, Singapore, Brazil, China, Turkey, Thailand, Malaysia, Mexico, India, South Africa and Philippines
Ahmed et al. (2019)	1971–2014	Japan
Alola et al. (2019)	1997–2014	16 European Union countries
Baloch et al. (2019)	1990–2016	59 Belt and Road countries
Chen et al. (2019)??	1991–2014	16 Central and Eastern European countries
Danish et al. (2019)	1971–2014	Pakistan
Danish et al. (2019)	1992–2016	BRICS countires
Dogan et al. (2019)	1971–2013	Mexico, Indonesia, Nigeria, Turkey
Wang and Dong (2019)	1990–2014	14 Sub-Sahara African countries
Altıntaş and Kassouri (2020)	1990–2014	14 European countries
Dogan et al. (2020)	1980–2014	Brazil, Russia, India, China, South Africa, Turkey
Nathaniel et al. (2020)	1990–2016	MENA countries
Sharif et al. (2020)	1965–2017	Turkey
Usman et al. (2020)	1994–2017	33 upper-middle-income countries
Jahanger et al. (2022)	1990–2016	73 developing countries
Faris Alruweili (2023)	1981–2017	Saudi Arabia
Eissa (2023)	1971-2022	Egypt
Javeed et al. (2023)	1990–2017	Asian countries
Mehmood et al. (2023)	1990–2022	Pakistan, India, Bangladesh, Nepal, and Sri Lanka
Dardouri and Smida (2023)	1961–2018	G7 countires
Magazzimo (2024)	1969–2019	China
Minh-Quang Nguyen et al. (2024)	1970–2018	Vietnam

Source: own elaboration.

3. Methodology

The article examined the annual economic growth rates and ecological footprint of the Central European countries, also known as the Visegrad Group countries: Poland, Czechia, Hungary, and Slovak Republic. The level of economic growth is measured by the size of the gross domestic product (GDP) per capita taken from the World Bank Indicators (https://databank.worldbank.org). This variable was calculated in constant prices from 2015 in USD (American dollars). Ecological footprint (EFP) data were extracted from the Global Footprint Network (https://data.footprintnetwork.org). This variable was calculated in global hectares per person (ghp per person). Both variables were collected from the 32-year period from 1990 to 2022. In order to examine the relationship between economic growth and ecological footprint, the following methods were used: analysis of the dynamics of the variables along with the determination of the trend line, descriptive statistics, Pearson correlation coefficient, and graphical construction of the environmental Kuznets curve. The analysis of the dynamics of variables was carried out by designating time intervals for those characterized by an upward trend and those with a downward trend. In addition, an attempt was made to designate a trend line that best describes the changes in both variables in the years 1990-2022, along with providing the value of the R_2 coefficient of determination. The closer the R_2 value to 1, the better the fit of the trend line. The following elements of descriptive statistics were selected for the comparative analysis of asymmetry and concentration measures of the distribution of GDP per capita and the ecological footprint per capita: mean, standard deviation, kurtosis, skewness, maximum and minimum values. Standard deviation is a measure of concentration, the high values of which indicate a high dispersion of variables. The second measure of concentration is kurtosis, the negativity of which indicates a platykurtic distribution (flattening less than normal), and positivity - a leptokurtic distribution (flattening greater than normal) (Puławska-Turyna, 2011). Skewness is a measure of the asymmetry of the distribution. Positive skewness means right-sided asymmetry, i.e. the existence of many values of the variable smaller than the mean, and negative means left-sided asymmetry, i.e. many variables are larger than the mean (Sobczak, 2007). Pearson correlation coefficient is a measure used to describe linear interdependence between two variables. Negative values of the coefficient mean an inverse relationship between variables, and positive values mean a positive relationship. The interpretation of the calculated absolute values of the coefficient is as follows: a) when smaller than 0,3 – weak correlation, b) when it is in the range of 0,4-0,6 – moderate correlation, c) when it is in the range of 0,7-0,9 – strong correlation, d) when = 1 – perfect correlation (Puławska-Turyna, 2011). An attempt was also made to construct EKC in order to deny or confirm the relationship between economic growth and ecological footprint for individual countries. For this purpose, an attempt was made to fit a trend line for the economic growth-ecological footprint relationship for each analyzed country. The trend line allowed to determine

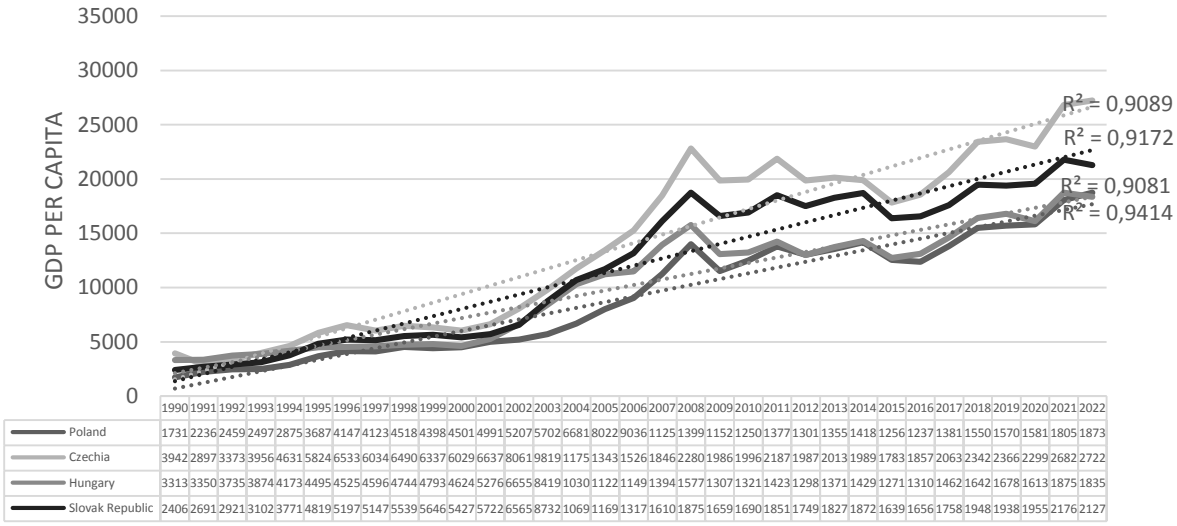
whether the relationship studied in individual countries is inverse-U-shaped, U-shaped, or N-shaped.

4. Results and discussion

The analysis of the relationship between economic growth and ecological footprint indicates its differentiation both over time and between the countries analyzed. In the analyzed period, both variables were not constant values in any of the countries. The dynamics of changes in economic growth measured by changes in GDP per capita between 1990 and 2022 were respectively in decreasing order: for Poland 9,8% for Slovakia 7,8%, for the Czechia 5,9% and for Hungary 4,5%. Although the increase in the growth of GDP per capita was the highest for Poland, the country was characterized by the lowest values of GDP per capita throughout the analyzed period, while the Czech economy was characterized by the highest values compared to other countries (Figure 1). Throughout the period analyzed, the ranking of countries, due to the level of economic growth, did not change. Figure 1 shows three characteristic time periods in which GDP per capita grew until 2008, then decreased until 2016. From 2016 to the end of the analyzed period, an upward trend can again be observed, with a noticeable decrease in this variable in the Hungarian and Slovak economies in 2022, compared to 2021. Despite these dynamics of change, a fairly strong linear trend in changes in GDP per capita could be matched for all economies, as shown in Figure 1. For all countries, the R_2 coefficient of determination for the linear trend line was over 0,9. The analysis of the dynamics of variables together with the determination of the trend line indicates the diversity of the variables studied in the analyzed countries. Table 2 presents the elements of descriptive statistics. Polish GDP per capita was characterized by the lowest value of this variable throughout the analyzed period: USD 1731,21 in 1990. The highest values of this variable occurred in the Czech economy: USD 27227 in 2022. In addition, the Czech economy experienced the greatest diversity in the level of this variable, having the highest standard deviation value. The Hungarian economy was characterized by the lowest variability, with the lowest standard deviation among the analyzed countries. The calculated kurtosis in all countries is negative, which means the platykurtic distribution of this variable. The calculated skewness was positive for Poland, the Czechia and Hungary, which means a right-skewed distribution. On the other hand, the Slovak economy was characterized by negative skewness, which means a left-skewed distribution.

The characteristics of the ecological footprint per capita for individual countries are completely different (Figure 2). The dynamics of changes in this variable between 1990 and 2022 were very small and amounted to, respectively, in decreasing order: for Czechia 0,9%, for Slovak Republic 0,6%, Poland 0,03%. Only for Hungary the dynamics of the ecological footprint was negative, at the level of -0,1%, which can be considered a positive phenomenon,

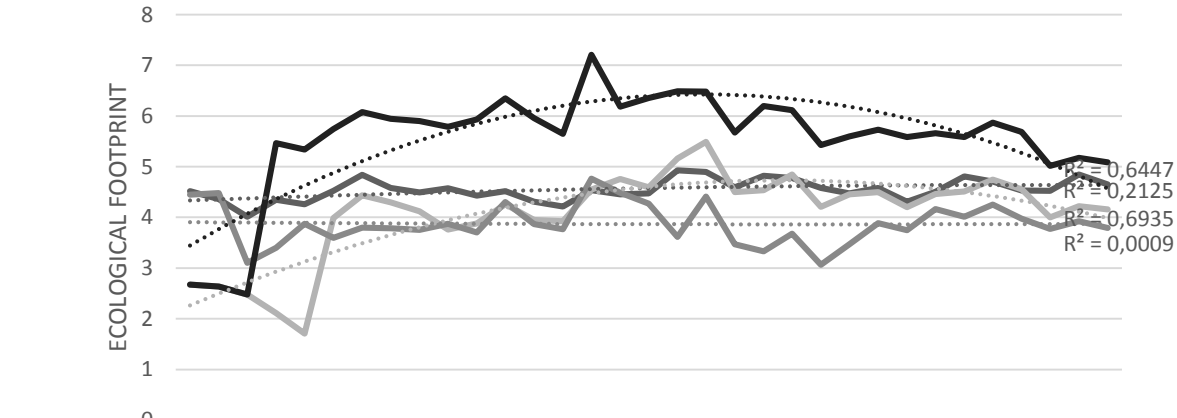
especially since this economy was characterized by the highest values of this variable at the beginning of the analyzed period, compared to other countries, and the lowest at the end. The opposite situation occurred in the Czech economy, where the ecological footprint value at the beginning of the analyzed period was the lowest, and the highest at the end. On the other hand, the lowest value of the ecological footprint per capita during the entire period was recorded by the Slovak economy: 1,70 ghp per capita in 1994, and the highest by the Czechia: 7,20 ghp per capita in 2004.



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Poland	1731	2236	2459	2497	2875	3687	4147	4123	4518	4398	4501	4991	5207	5702	6681	8022	9036	1125	1399	1152	1250	1377	1301	1355	1418	1256	1237	1381	1550	1570	1581	1805	1873
Czechia	3942	2897	3373	3956	4631	5824	6533	6034	6490	6337	6029	6637	8061	9819	1175	1343	1526	1846	2280	1986	1996	2187	1987	2013	1989	1783	1857	2063	2342	2366	2299	2682	2722
Hungary	3313	3350	3735	3874	4173	4495	4525	4596	4744	4793	4624	5276	6655	8419	1030	1122	1149	1394	1577	1307	1321	1423	1298	1371	1429	1271	1310	1462	1642	1678	1613	1875	1835
Slovak Republic	2406	2691	2921	3102	3771	4819	5197	5147	5539	5646	5427	5722	6565	8732	1069	1169	1317	1610	1875	1659	1690	1851	1749	1827	1872	1639	1656	1758	1948	1938	1955	2176	2127

Figure 1. GDP per capita between 1990 and 2022.

Source: own elaboration.



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
POLAND	4,51	4,36	4,01	4,35	4,26	4,52	4,84	4,58	4,49	4,57	4,43	4,52	4,31	4,22	4,54	4,45	4,47	4,93	4,89	4,59	4,82	4,78	4,58	4,47	4,58	4,31	4,51	4,8	4,71	4,53	4,52	4,85	4,65
SLOVAK REPUBLIC	2,68	2,63	2,48	2,11	1,71	3,99	4,44	4,3	4,12	3,76	3,88	4,26	3,95	3,93	4,55	4,76	4,59	5,16	5,49	4,5	4,53	4,85	4,21	4,46	4,5	4,2	4,46	4,51	4,74	4,55	4	4,22	4,16
HUNGARY	4,45	4,48	3,11	3,4	3,87	3,59	3,8	3,78	3,75	3,87	3,7	4,3	3,87	3,76	4,76	4,48	4,27	3,61	4,41	3,47	3,33	3,68	3,06	3,47	3,89	3,75	4,16	4,01	4,25	3,97	3,77	3,92	3,79
CZECHIA	2,68	2,63	2,48	5,47	5,34	5,74	6,08	5,94	5,9	5,79	5,93	6,35	5,95	5,65	7,21	6,19	6,36	6,49	6,48	5,68	6,19	6,11	5,42	5,59	5,73	5,59	5,66	5,59	5,87	5,68	5,02	5,18	5,08

Figure 2. Ecological footprint per capita between 1990 and 2022.

Source: own elaboration.

Table 2.
Descriptive statistics for GDP per capita

VARIABLES	COUNTRIES			
	Poland	**Czechia**	**Hungary**	**Slovak Republic**
MEAN	9567.361	14572.44	10584.41	12384.77
STANDARD DEVIATION	5666.822	8315.069	5466.345	6955.877
KURTOSIS	-1.06988	-1.40482	-1.2008	-1.58551
SKEWNESS	0.264226	0.066633	0.094323	-0.09031
MIN VALUE	1731,21	2896,609	3312,698	2405.535
MAX VALUE	22112.86	30427.42	22147.21	24470.24

Source: own elaboration.

Table 3.
Descriptive statistics for ecological footprint per capita

VARIABLES	COUNTRIES			
	Poland	**Czechia**	**Hungary**	**Slovak Republic**
MEAN	4.544061	5.546837	3.873667	4.080691
STANDARD DEVIATION	0.208283	1.045493	0.40066	0.847133
KURTOSIS	0.184548	4.246947	-0.13495	1.674282
SKEWNESS	-0.15262	-2.01189	0.148992	-1.36718
MIN VALUE	4.0126	2.479515	3.063932	1.708239
MAX VALUE	4.926065	7.2074	4.763823	5.490977

Source: own elaboration.

Analyzing the changes in the ecological footprint value in the time series, four periods of increasing and decreasing trends was observed. The first period, in which the largest increases in the value of the variable occurred, lasted until 2004. After that year, the value of the ecological footprint per capita systematically decreased until 2012, and then increased until 2019. From 2020, lower and lower values of this variable were observed until the end of the period analyzed. The variability characteristics of the distribution of the ecological footprint per capita make determining a linear trend line ineffective. The R_2 values describing the linear trend oscillated around very low value: 0,1. A better fit was obtained by fitting a polynomial trend line. At that time, the R_2 values were at a level of about 0,6. The greatest variation in the ecological footprint value, with the simultaneous occurrence of the highest standard deviation value among the analyzed countries, characterized the economy of Czechia (Table 3), while the lowest variability of this variable was related to the Polish economy, with the lowest standard deviation value among the analyzed countries. The calculated measures of concentration and asymmetry of the distribution for the ecological footprint also yield values different from those of the distribution of GDP per capita. The economies of Poland, Czechia and the Slovak Republic were characterized by positive kurtosis and negative skewness, which means the leptokurtic distribution and its left sidedness. The inverse values of kurtosis and skewness calculated for the Hungarian economy indicate the platykurtic distribution of the analyzed variable and its right-sidedness. The analysis of the values calculated using descriptive statistics shows the diversification of the results obtained for the selected countries and variables.

Table 4 presents the relationships between changes in GDP per capita and changes in the ecological footprint per capita and the Pearson correlation coefficients between these variables in the analyzed period. The results varied both in terms of time and country. In most cases, the coefficient values were higher than 0,5, which indicates a moderate correlation. The highest values of the coefficient, above 0,7, indicating a strong correlation, referred to the period 2009-2016. In the years 1990-2016, a positive correlation can be observed in all analyzed countries. In the years 2017 to 2022, the correlation between the variables was negative, with moderate strength. For the Polish economy, the values of the correlation coefficient for all distinguished periods were positive, although very low. Therefore, smaller time ranges were distinguished, which increased the values of this coefficient, especially for the years 2020-2022. The separation of four periods for the other economies did not bring better results than the separation of three ones. The use of Pearson correlation coefficient provides a basis for confirming the existence of a relationship, positive mostly, between economic growth and economic footprint. This is consistent with many works showing the existence of a relationship between economic growth and ecological footprint.

Table 4.
GDP per capita, ecological footprint per capita and Pearson correlation coefficients

CONUNTRY	VARIABLES	PERIODS			
		1990-2008	2009-2016	2017-2022	
POLAND	GDP PER CAPITA	7.08	-0.12	0.51	
	FOOTPRINT PER CAPITA	0.08	-0.08	0.03	
	CORRELATION COEFFICIENT	0.60	0.32	0.34	
		1990-2004	2005-2012	2013-2019	2020-2022
		0.24	0.69	0.46	0.73
CZECHIA	GDP PER CAPITA	4.79	-0.19	0.47	
	FOOTPRINT PER CAPITA	1.42	-0.13	-0.10	
	CORRELATION COEFFICIENT	0.57	0.75	-0.55	
HUNGARY	GDP PER CAPITA	3.76	-0.17	0.40	
	FOOTPRINT PER CAPITA	-0.01	-0.06	-0.09	
	CORRELATION COEFFICIENT	0.37	0.63	-0.52	
SLOVAK REPABLIC	GDP PER CAPITA	6.80	-0.12	0.28	
	FOOTPRINT PER CAPITA	1.05	-0.19	-0.07	
	CORRELATION COEFFICIENT	0.79	0.60	-0.45	

Source: own elaboration.

Figure 3 presents the graphical relationships between GDP per capita and ecological footprint per capita in the years 1990-2022 in analyzed countries. An attempt was made to fit a trend line for the economic growth-ecological footprint relationship for each analyzed economy. The best fit for all countries turned out to be a polynomial trend line. Although it is not a perfect fit, especially for the Hungarian economy. Analyzing the graphs, it can be seen that for Slovak Republic and Czechia the curve was inverted-U-shaped, and for the economies of Hungary and Poland the curve was N-shaped.

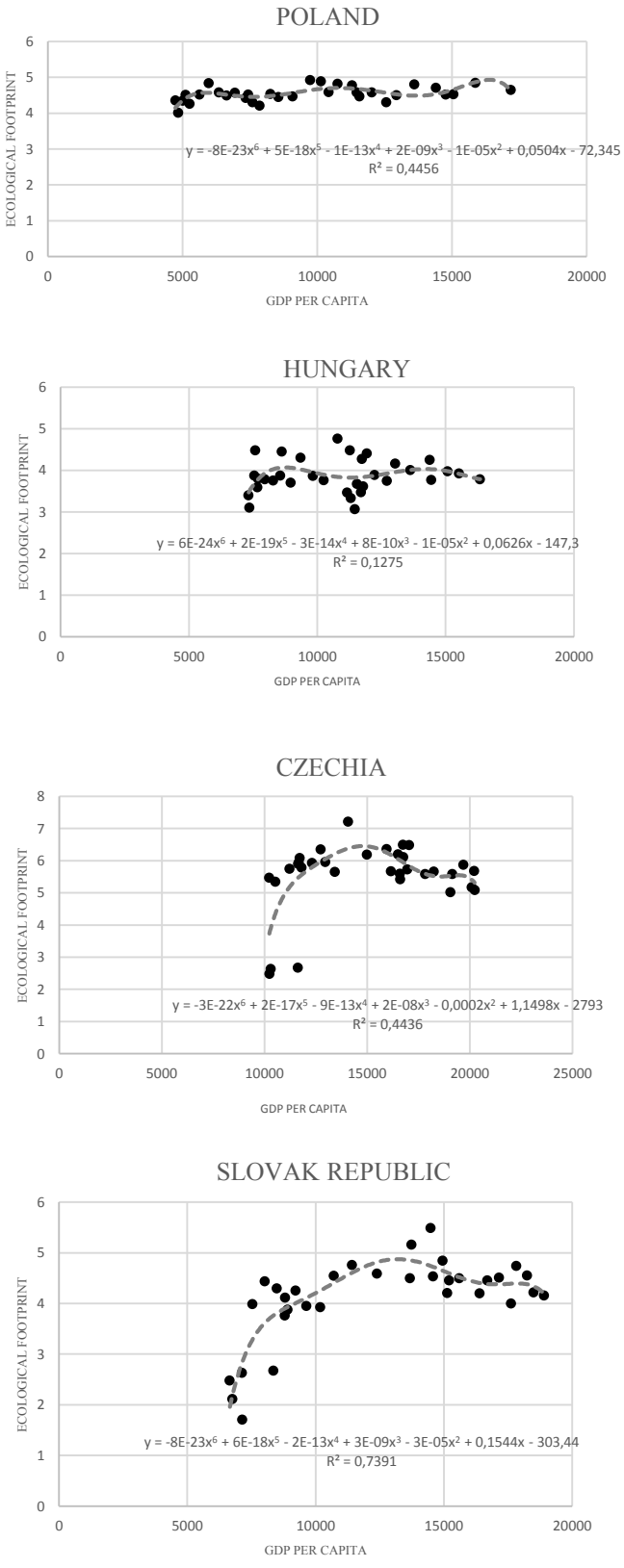


Figure 3. Relation between GDP per capita and ecological footprint and EKC.
Source: own elaboration.

The results obtained confirm the presence of the economic growth-ecological footprint relationship and the possibility of describing it using EKC. This conclusion is consistent with most works examining this relationship. The research conducted in this work also confirmed the non-linear relationship of both variables, which is also consistent with the work of other researchers. In addition, it was proven that the environmental Kunzets curve can be U-shaped and N-shaped, which is also confirmed by other authors referring to many economies around the world. The existence of differentiation of the analyzed relationship between the Eastern European countries was also confirmed. However, the conclusions regarding the shape of the EKC were not fully confirmed. The N-shaped EKC of Poland and the inverted-U-shaped EKC of the Czechia coincide with the conclusions obtained by Lazar et al. (2019). Saud et al. (2019) who also confirmed its existence, but only for Poland and the Slovak Republic. The obtained positive values of the Pearson coefficient confirm the existence of a positive relationship between economic growth and ecological footprint in the initial time range, which is consistent with the results obtained by Jamel et al. (2017) and Destek et al. (2018).

5. Summary

This article analyzed the annual indicators of gross domestic product per capita and ecological footprint of Central European countries: Poland, Czechia, Hungary and Slovak Republic. Both variables were collected over a 32-year period from 1990 to 2022. In order to examine the relationship between economic growth and ecological footprint, the following were used: analysis of the dynamics of the course of variables, descriptive statistics, Pearson correlation coefficient and graphical construction of the environmental Kuznets curve. The analysis of the relationship between economic growth and ecological footprint in Central European countries indicates its diversification both over time and between the analyzed countries. Analysis of values calculated using descriptive statistics showed diversification of the results obtained for selected countries and variables. The use of Pearson correlation coefficient provided a basis for confirming the existence of a relationship between economic growth and economic footprint. In the years 1990-2016, a positive correlation could be observed in all countries analyzed. In the years 2017 to 2022, the correlation between variables was negative. The obtained results also confirm the presence of a non-linear relationship between economic growth and ecological footprint and the possibility of describing it using EKC, which for the Slovak Republic and Czechia took shape of an inverted-U, while for the economies of Hungary and Poland the EKC curve was N-shaped.

References

1. Acheampong, A., Opoku, E. (2023). Environmental Degradation and Economic Growth: Investigating Linkages and Potential Pathways. *Energy Economics, Vol. 123*, doi.org/10.1016/j.eneco.2023.106734.
2. Addai, K., Genç, S.Y., Castanho, R.A., Couto, G., Orhan, A., Umar, M., Kirikkaleli, D. (2023). Financial Risk and Environmental Sustainability in Poland: Evidence from Novel Fourier-Based Estimators. *Sustainability, Vol. 15, Iss. 7,* pp. 5801, doi.org/10.3390/ su15075801.
3. Ahmed, Z., Zhang, B., Cary, M. (2021). Linking economic globalization, economic growth, financial development, and ecological footprint: Evidence from symmetric and asymmetric ARDL. *Ecological Indicators, Vol. 121,* doi.org/10.1016/j.ecolind.2020. 107060.
4. Ahmet, A.A, Sevil, A. (2016). Does income growth relocate ecological footprint? *Ecological Indicators, Vol. 61, Part 2,* pp. 707-714, doi.org/10.1016/j.ecolind.2015.10. 022.
5. Al-Mulali, U., Ozturk, I. (2015). The Effect of Energy Consumption, Urbanization, Trade Openness, Industrial Output, and the Political Stability on the Environmental Degradation in the MENA (Middle East and North African) Region. *Energy, Vol. 84,* pp. 382-389, doi.org/10.1016/j.energy.2015.03.004.
6. Alola, A.A., Bekun, F.V., Sarkodie. S.A. (2019). Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe. *The Science of the total environment*, *Vol. 685*, pp. 702-709, doi.org/10.1016/j.scitotenv.2019.05.
7. Alruweili F. (2023). Impact of GDP growth on the ecological footprint: Theoretical and empirical evidence from Saudi Arabia. *International Journal of Advanced And Applied Sciences, Vol. 10,* pp. 120-129, doi:10.21608/MSAMSJ.2023.257398.1047.
8. Altıntaş, H., Kassouri, Y. (2020). Is the environmental Kuznets Curve in Europe related to the per-capita ecological footprint or CO2 emissions? *Ecological Indicators, Vol. 113*, doi.org/10.1016/j.ecolind.2020.106187.
9. Baabou, W., Grunewald, N., Ouellet-Plamondon, C., Gressot, M., Galli, A. (2017). The Ecological Footprint of Mediterranean cities: Awareness creation and policy implications. *Environmental Science & Policy, Vol. 69,* pp. 94-104, doi:10.1016/j. envsci.2016.12.013.
10. Baloch, M.A., Zhang, J., Iqbal, K., Iqbal, Z. (2019). The effect of financial development on ecological footprint in BRI countries: evidence from panel data estimation. *Environmental Science and Pollution Research, Vol. 26*, pp. 6199-6208, doi:10.1007/s11356-023-27573-2.

11. Barro, R.J., Sala-i-Martin, X. (2001). *Economic Growth.* Cambridge: The MIT Press.
12. Bello, M.O., Solarin, S.A., Yen, Y.Y. (2018). The impact of electricity consumption on CO_2 emission, carbon footprint, water footprint and ecological footprint: The role of hydropower in an emerging economy. *Journal of Environmental Management, Vol. 219,* doi:10.1016/j.jenvman.2018.04.101.
13. Borucke, M., Moore, D., Cranston, G., Gracey, K., Iha, K., Larson, J., Lazarus, E., Morales, J.C., Wackernagel, M., Galli, A. (2013). Accounting for demand and supply of the biosphere's regenerative capacity: The National Footprint Accounts' underlying methodology and framework. *Ecological Indicators, Vol. 24,* pp. 518-533, doi:10.1016/j.ecolind.2012.08.005.
14. Chaabouni, S., Zghidi, N., Mbarek, M. (2016). On the causal dynamics between CO2 emissions, health expenditures and economic growth. *Sustainable Cities and Society, Vol. 22,* pp. 184-191, doi:10.1016/j.scs.2016.02.001.
15. Charfeddine, L., Mrabet, Z. (2017). The Impact of Economic Development and Social-Political Factors on Ecological Footprint: A Panel Data Analysis for 15 MENA Countries. *Renewable Sustainable Energy Reviews, Vol. 76,* pp. 138-154, doi:10.1016/j.rser. 2017.03.031.
16. Danish, S., Hassan, T., Muhammad A.B., Nasir M., Zhang I. (2019). Linking economic growth and ecological footprint through human capital and biocapacity. *Sustainable Cities and Society, Vol. 47,* doi:10.1016/j.scs.2019.101516.
17. Dardouri, N., Smida, M. (2023). The Link between Economic Growth and Ecological Footprint: What Future Prospects for the G7 Countries: PMG-ARDL. *Migration Letters, Vol. 20, Iss. S12,* pp. 50-65, doi:10.59670/ml.v20iS12.5841.
18. Destek, M., Ulucak, R., Dogan, E. (2018). Analyzing the environmental Kuznets curve for the EU countries: the role of ecological footprint. *Environmental Science and Pollution Research, Vol. 25,* pp. 29387-29396, doi:10.1007/s11356-018-2911-4.
19. Destek, M.A., Sarkodie, S.A. (2019). Investigation of environmental Kuznets curve for ecological footprint: The role of energy and financial development. *The Science of the total environment, Vol. 650, Iss. 2,* pp. 2483-2489, doi:10.1016/j.scitotenv.2018.10.017.
20. Dogan, E., Taspinar, N., Gokmenoglu, K.K. (2019). Determinants of ecological footprint in MINT countries. *Energy & Environment, Vol. 30 Iss. 6,* pp.1065-1086, doi:10.1016/j. envc.2022.100467.
21. Eissa, A.A. (2023). Investigating ther relationship between economic growth and ecological footprint in Egypt. *MSA-Management Science Journal, Vol. 2, Iss. 3,* pp. 112-145, doi: 10.21608/MSAMSJ.2023.257398.1047.
22. Feng, Z., Wu, J. (2011). *Relationship between the ecological footprint and the economic growth in China.* International Conference on Remote Sensing, Environment and Transportation Engineering, Nanjing, China, pp. 6205-6211, doi: 10.1109/RSETE.2011. 5965775.

23. Genstwa, N. (2020) Środowiskowa krzywa Kuznetsa: przegląd teoretyczno-metodyczny. *Rozwój Regionalny i Polityka Regionalna, Vol. 49,* pp. 39-60, doi:10.14746/rrpr. 2020.49.04.
24. Grossman, G.M., Krueger, A.B. (1995). Economic growth and the environment. *Quarterly Journal of Economics, Vol. 110, Iss. 2,* pp. 353-377, doi: 10.2307/2118443.
25. Gruszecki, L., Jóźwik, B. (2019). Teoretyczne rekonstrukcje środowiskowej krzywej Kuznetsa. *Gospodarka Narodowa. The Polish Journal of Economics, Vol. 299, Iss. 3,* pp. 95-117, doi:10.33119/GN/111469.
26. Harrod, R.F. (1973). *Economics Dynamic*. London: Macmillian.
27. https://data.footprintnetwork.org/
28. https://databank.worldbank.org/source/world-development-indicators
29. Jahanger, A., Usman, M., Murshed, M., Mahmood, H., Balsalobre-Lorente, D. (2022). The linkages between natural resources, human capital, globalization, economic growth, financial development, and ecological footprint: The moderating role of technological innovations. *Resources Policy, Vol. 76, 102569*, doi:10.1016/j.resourpol.2022.102569.
30. Jamel, L., Maktouf, S. (2017). The nexus between economic growth, financial development, trade openness, and CO2 emissions in European countries. *Cogent Economics & Finance, Vol. 5, Iss. 1,* doi:10.1080/23322039.2017.1341456
31. Jammazi, R., Aloui, Ch. (2015). On the interplay between energy consumption, economic growth and CO2 emission nexus in the GCC countries: A comparative analysis through wavelet approaches. *Renewable and Sustainable Energy Reviews, Elsevier, Vol. 51,* pp. 1737-1751, doi: 10.1016/j.rser.2015.07.073.
32. Javeed, S., Siddique, H.M.A., Javed, F. (2023). Ecological footprint, globalization, and economic growth: evidence from Asia. *Environmental science and pollution research international*, *Vol. 30, Iss. 31*, pp. 77006-77021, doi:10.1007/s11356-023-27754-z.
33. Kłos, L. (2014). Ślad ekologiczny jako nieekonomiczny miernik jakości życia społeczeństwa. *Studia Ekonomiczne*, *Vol. 166*, pp. 67-77.
34. Kuznets, S. (1971). *Economic Growth of Nations. Total Output and Production Structure*, Cambridge: Harvard University Press.
35. Lazăr, D., Minea, A., Purcel, A.A. (2019). Pollution and economic growth: Evidence from Central and Eastern European countries. *Energy Economics, Vol. 81,* pp. 1121-1131, doi:10.1016/j.eneco.2019.05.011.
36. Lewis, W.A. (1963). *The Theory of Economic Growth*. London: George Allen and Unwin.
37. Magazzino, C. (2024). Ecological footprint, electricity consumption, and economic growth in China: geopolitical risk and natural resources governance. *Empir. Econ., Vol.* 66, pp. 1-25, doi:10.1007/s00181-023-02460-4.
38. Mehmood, U., Aslam, M.U., Javed, M.A. (2023). Associating Economic Growth and Ecological Footprints through Human Capital and Biocapacity in South Asia. *World, Vol. 4, Iss. 3,* pp. 598-611, doi:10.3390/world4030037.

39. Mrabet, Z., Alsamara, M. (2017). Testing the Kuznets Curve hypothesis for Qatar: A comparison between carbon dioxide and ecological footprint. *Renewable and Sustainable Energy Reviews, Elsevier, Vol. 70(C),* pp. 1366-1375, doi:10.1016/j.rser.2016.12.039.
40. Nathaniel, S.P. (2021). Natural Resources, Urbanization, Economic Growth and the Ecological Footprint in South Africa: The Moderating Role of Human Capital. *Quaestiones Geographicae, Adam Mickiewicz University, Vol. 40, Iss. 2,* pp. 63-76, doi:10.2478/quageo-2021-0012.
41. Nguyen, M.Q., Dimou, M., Huong Vu, T.T., Schaffar A. (2024). Testing the ecological footprint of economic growth in developing countries. The case of Vietnam. *Journal of International Development, Vol. 36, Iss. 5.* John Wiley and Sons, Ltd., pp. 2457-2477, doi:10.1002/jid.3918.
42. Osabuohien, E.S., Efobi, U.R., Gitau, C.M.W. (2014). Beyond the Environmental Kuznets Curve in Africa: Evidence from Panel Cointegration. *Journal of Environmental Policy & Planning, Vol. 16, Iss. 4,* pp.517-538, doi: 10.1080/1523908X.2013.867802.
43. Ozturk, I., Acaravci, A. (2010). CO2 emissions, energy consumption and economic growth in Turkey. *Renewable and Sustainable Energy Reviews, Vol. 14, Iss. 9,* pp. 3220-3225 doi:10.1016/j.rser.2010.07.005.
44. Panayotou, T. (1993). *Empirical tests and policy analysis of environmental degradation at different stages of economic development.* ILO Working Papers. International Labour Organization.
45. Pułaska-Turyna, B. (2011). *Statystyka dla ekonomistów.* Warszawa: Difin.
46. Raihan, A., Voumik, L.C., Zimon, G., Sadowska, B., Rashid, M., Akter, S. (2024). Prioritising sustainability: how economic growth, energy use, forest area, and globalization impact on greenhouse gas emissions and load capacity in Poland? *International Journal of Sustainable Energy, Vol. 43, Iss. 1,* doi:*10.1080/14786451.2024.2361410*.
47. Rogall, H. (2010). *Ekonomia zrównoważonego rozwoju. Teoria i praktyka*. Poznań: Zysk i S-ka.
48. Romer, D. (2005). *Advanced Macroeconomics.* New York: McGraw-Hill.
49. Rostow, W.W. (1953). *The Process of Economic Growth.* Oxford: Clarendon Press.
50. Saud, S., Chen, S., Haseeb, A., Khan, K., Imran, M. (2019). The nexus between financial development, income level, and environment in Central and Eastern European Countries: a perspective on Belt and Road Initiative. *Environmental science and pollution research international, Vol. 26, Iss.16,* pp. 16053-16075, doi:10.1007/s11356-019-05004-5.
51. Sobczyk, M. (2007). *Statystyka.* Warszawa: PWN.
52. Solow R.M. (2000). *Growth Theory. An Exposition.* New York/Oxford: University Press.
53. Uddin, G., Salahuddin, M., Alam, A., Gow, J., (2017). Ecological footprint and real income: panel data evidence from the 27 highest emitting countries. *Ecological Indicators Vol. 77*, pp.166-175, doi:10.1016/j.ecolind.2017.01.003.

54. Ulucak, R. Bilgili, F. (2018). A Reinvestigation of EKC Model by Ecological Footprint Measurement for High, Middle and Low Income Countries. *Journal of Cleaner Production, Vol. 188,* pp.144-157, doi:10.1016/j.scs.2019.101626.
55. Usman, M., Kousar, R., Yaseen, M., Makhdum, M. (2020). An empirical nexus between economic growth, energy utilization, trade policy, and ecological footprint: a continent-wise comparison in upper-middle-income countries. *Environmental Science and Pollution Research, Vol. 27, Iss. 31,* pp. 38995-39018, doi:10.1007/s11356-020-09772-3.
56. Wackernagel, M., Kitzes, J. (2008). *Ecological Footprint, Editors: S.E. Jørgensen, Brian D. Fath, Encyclopedia of Ecology.* Academic Press, pp. 1031-1037, doi: 10.1016/B978-008045405-4.00620-0.
57. Wackernagel, M., Rees, W.E. (1996). *Our Ecological Footprint: Reducing Human Impact on the Earth*. Philadelphia: New Society Publishers.
58. Wang, Y.C. (2013). Functional sensitivity of testing the environmental Kuznets curve hypothesis. *Resource and Energy Economics, Vol. 35, Iss. 4,* pp. 451-466, doi:10.1016/j. reseneeco.2013.01.003.
59. Woźniak, M.G. (2004). *Wzrost gospodarczy. Podstawy teoretyczne*. Kraków: AE Kraków.
60. Zaidi, S., Saidi, K. (2018). Environmental pollution, health expenditure and economic growth in the Sub-Saharan Africa countries: Panel ARDL approach. *Sustainable Cities and Society, Vol. 41,* pp. 833-840, doi:10.1016/j.scs.2018.04.034.

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CLASSIFICATION OF LARGE EUROPEAN CITIES BASED ON THE RATINGS OF THEIR INHABITANTS

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Purpose: Trends indicate an increasing share of the population living in an urbanized world. It is important to provide them with appropriate living conditions. Most often, we describe living conditions using objective indicators. We hope that they reflect the expectations of the residents well. What if this is not the case? The aim of the research presented in the article is to provide a classification of large European cities based on the opinions of their inhabitants.
Design/methodology/approach: Eurostat provides data from the Perception Survey on the Quality of Life in European Cities. The research is carried out every four years. The last was in 2023.
Findings: The existence of three types of large European cities covered by the study was indicated.
Research limitations/implications: The results of the research are based on subjective assessments of the residents, perhaps they should be verified with objective factors.
Social implications: A work to look at cities through the eyes of their inhabitants. It shows the similarities in their perception of the conditions resulting from the location of the city and the economic conditions of the state.
Originality/value: Application of clustering methods to the analyzed data, determination of groups of similar cities. Defining the dimensions in the PCA analysis that cities can be described.
Keywords: PCA, K-means, Eurostat, European Cities, Quality of Life.
Category of the paper: Research paper.

1. Introduction

In 2023, the degree of urbanization worldwide was 57 percent. North America, Latin America, and the Caribbean had the highest level of urbanisation, about 83 percent. Next was Europe, with 75 percent. North America is the most urbanized continent, but Tokyo-Yokohama in Japan was the largest urban area in the world that year, with 37.7 million inhabitants.

Cities are the future of the population. The possibility of using modern technologies has become the foundation of the Smart City concept. It was quickly noticed that an IT-only approach was not enough. This can be seen by following the development of the Smart City concept: (Cohen, 2015; Svítek et al., 2020; Kinelski, 2022; Kuzior, 2024):

- Smart City 1.0 – the ICT sector offers its products for cities.
- Smart City 2.0 – cities are the initiators of ICT implementation.
- Smart City 3.0 – city citizens take over the initiative to implement ICT solutions.
- Smart City 4.0 – knowledge sharing modern technologies ensure sustainable development of urban areas and their inhabitants.
- Smart City 5.0 – a multi-agent ecosystem of smart services allows for a harmonious balance of various aspects of residents' lives.

The diversity of the approach to Smart City has allowed us to dimension of smart city. The classic ones include (Cohen, 2015; Giffinger, Gudrun, 2010; Marchlewska-Patyk, 2023):

- economy – actions aimed at transforming and strengthening the city's economy,
- environment – environmental management to improve living standards and reduce civilization pollution,
- government – interaction between the city authorities and all stakeholders – citizens, entrepreneurs, civil society organizations,
- living – improving quality of life, social and digital exclusion, safety and care,
- mobility – urban transport services, improving the flow of people, goods and services in the city,
- people – appropriate forms of education, career opportunities in labor markets.

The appearance of dimensions coincided with the appearance of rankings evaluating cities. These tools can be used to plan development, assess your strengths and weaknesses against other similar cities. A high position in the ranking is what the city can boast about in order to attract new investors and develop tourism (Akande et al., 2019; Pangsy-Kania, Kania, 2024; Berger, 2019; Toh, 2022; Vanli, 2024).

The need to take into account the socio-economic dimension has been noted in the development (Jonek-Kowalska, 2019). In this dimension, it is the human being who is most important for the development of the city. His needs are in the foreground. Large cities are the location of higher education centers. Graduates very often stay in the city where they studied, creating a base of people that should play a significant role in the development of the city. The city should meet their living needs as well as further development.

2. Data structure

The Perception Survey on the Quality of Life in European Cities was conducted in 79 European cities. It covered all capitals of the countries studied (except Switzerland) and one to six additional cities in larger countries. About 500 residents were interviewed in each city, and 835 interviews were collected in each city. Targets were set at a minimum of 100 online interviews per city and a maximum of 735 via telephone. In some cities, more online interviews were collected.

The Eurostat database includes 82 European cities with at least 500,000 inhabitants. Not all of them are included in the quality of life survey. By limiting the original collection of cities the following cities were received: Amsterdam, Ankara, Antalya, Antwerpen, Athens, Barcelona, Berlin, Bordeaux, Brussel, Bucharest, Budapest, Copenhagen, Diyarbakir, Dortmund, Dublin, Essen, Geneve, Glasgow, Hamburg, Helsinki, Istanbul, Krakow, Leipzig, Lille, Lisbon, London, Madrid, Malaga, Manchester, Marseille, Munchen, Napoli, Oslo, Palermo, Paris, Prague, Riga, Rome, Rotterdam, Sofia, Stockholm, Stuttgart, Torino, Vilnius, Warsaw, Wien, Zurich. Not all cities can be considered strictly European, but it was decided that they should be left in the study due to their membership in the EU or NATO community.

Due to the specificity of the available data, new areas of city assessment have been defined.

- **ECONOMY** (ECO) – questions about work, real estate prices, the financial and material situation of the household.
- **ENVIRONMENT** (ENV) – here are the assessments of green space, noise and air quality.
- **GOVERNANCE** (GOV) – assessment of satisfaction with solving local problems, procedures applied by the city authorities, information and administrative services, corruption of local authorities.
- **HUMAN CAPITAL** (HUC) – sports and cultural activities as well as facilities offered by the city, education.
- **QUALITY OF LIFE** (QLI) – trust in other residents, satisfaction with life in the city, assessment of the city as a place to live.
- **SOCIAL COHESION INDICATORS** (SCI) – health care, safety, friendliness towards immigrants, minorities, LGBT communities, non-material help.
- **TRANSPORT** (TRN)- diverse evaluation of urban transport.

Based on the Eurostat database, the following set of indicators has been proposed (table 1).

Table 1.
Indicators for the assessment of cities

ID	Questions with answer variants and weights
ECO_01	In this city it is easy to find a good job: [2, 1, -1, -2, 0]
ECO_02	In this city, it is easy to find good housing at a reasonable price: [2, 1, -1, -2, 0]
ECO_03	The financial situation of your household: [2, 1, -1, -2, 0]
ECO_04	If you needed material help (e.g. money, loan or an object) you could receive it from relatives, friends, neighbours or other persons you know: [1, 0, 0]
ECO_05	Your personal job situation: [2, 1, -1, -2, 0]
ECO_06	Within the last 12 months, would you say you had difficulties to pay your bills at the end of the month: [-2, -1, 1, 0]
ENV_01	Green spaces such as public parcs or gardens: [2, 1, -1, -2, 0]
ENV_02	The quality of the air in the city: [2, 1, -1, -2, 0]
ENV_03	The noise level in the city: [2, 1, -1, -2, 0]
ENV_04	The cleanliness in the city: [2, 1, -1, -2, 0]
GOV_01	I am satisfied with the amount of time it takes to get a request solved by my local public administration: [2, 1, -1, -2, 0]
GOV_02	The procedures used by my local public administration are straightforward and easy to understand: [2, 1, -1, -2, 0]
GOV_03	Information and services of my local public administration can be easily accessed online: [2, 1, -1, -2, 0]
GOV_04	There is corruption in my local public administration: [-2, -1, 1, 2, 0]
GOV_05	The fees charged by my local public administration are reasonable: [2, 1, -1, -2, 0]
HUC_01	Sports facilities such as sport fields and indoor sport halls in the city: [2, 1, -1, -2, 0]
HUC_02	Cultural facilities such as concert halls, theatres, museums and libraries in the city: [2, 1, -1, -2, 0]
HUC_03	Schools and other educational facilities: [2, 1, -1, -2, 0]
QLI_01	Generally speaking, most people in this city can be trusted: [2, 1, -1, -2, 0]
QLI_02	Most people in my neighbourhood can be trusted: [2, 1, -1, -2, 0]
QLI_03	I'm satisfied to live in this city: [2, 1, -1, -2, 0]
QLI_04	The neighbourhood where you live: [2, 1, -1, -2, 0]
QLI_05	For people in general: a good place to live; not a good place to live; don't know/no answer/refuses: [2, 1, 0]
QLI_06	Public spaces in this city such as markets, squares, pedestrian areas: [2, 1, -1, -2, 0]
QLI_07	The life you lead: [2, 1, 1, -2, 0]
QLI_08	How is your health: [2, 1, 0, -1, -2, 0]
QLI_09	How much of the time, during the past 4 weeks, have you been feeling lonely: [-5, -4, -4, -2, 0, -1, 0]
QLI_10	How much of the time, during the past 12 months, have you been feeling lonely: [-5, -4, -3, -2, 0, -1, 0]
QLI_11	Compared to five years ago quality of life in your city or area has: [-2, 0, 2, 0]
SCI_01	Health care services, doctors and hospitals: [2, 1, -1, -2, 0]
SCI_02	I feel safe walking alone at night in my city: [2, 1, -1, -2, 0]
SCI_03	For racial and ethnic minorities: [-1, -2, 0]
SCI_04	For gay or lesbian people: [2, 1, 0]
SCI_05	For immigrants from other countries: [-1, -2, 0]
SCI_06	Confidence in the local police force: [1, 0, 0]
SCI_07	Money or property stolen from you or another household member in your city the last 12 months: [0, 1, 0]
SCI_08	Being assaulted or mugged in your city the last 12 months: [0, 1, 0]
SCI_09	If you needed non material help (e.g. somebody to talk to, help with doing something or collecting something) you could receive it from relatives, friends, neighbours or other persons you know: [1, 0, 0]
SCI_10	I feel safe walking alone at night in my neighbourhood: [2, 1, -1, -2, 0]
SCI_11	For young families with children: [2, -2, 0]
SCI_12	For elderly people: a good place to live: [2, -2, 0]
TRP_01	Public transport in the city, for example bus, tram or metro: [2, 1, -1, -2, 0]

Cont. table 1.

TRP_02	Means of transport most often used: car; motorcycle; bicycle; foot; train; urban public transport; other; do not commute; don't know / no answer / refuses: [0, 0, 0, 0, 0, 1, 0, 0, 0]
TRP_03	Public transport affordable: [2, 1, -1, -2, 0]
TRP_04	Public transport safe: [2, 1, -1, -2, 0]
TRP_05	Public transport easy to get: [2, 1, -1, -2, 0]
TRP_06	Public transport frequent (comes often): [2, 1, -1, -2, 0]
TRP_07	Public transport reliable (comes when it says it will): [2, 1, -1, -2, 0]

Source: Eurostat, The Perception Survey on the Quality of Life in European Cities – questions.

3. Methods

The answers to the questions are predominantly on a 5-point Likert scale. Each question is accompanied by the weights applied to each answer. The database shows the percentage of citizens choosing individual categories. Weighted answers to each question were determined, thus obtaining the indicator's value. The scales have been selected so that a larger value of the indicator shows the greater importance of the indicator.

Then, the obtained values were normalized using a formula that took into account the worst and best assessments in each of the studied periods.

The formula used is min-max normalisation:

$$norm(x_i) = (100 - 50)\frac{x_i - \min\limits_k(x_k)}{\max\limits_k(x_k) - \min\limits_k(x_k)} + 50 \tag{1}$$

After the first stage of normalization and determination of the mean value of the criterion, the criterion was normalized again.

$$u(x_i) = \frac{x_i - mean(x)}{sd(x)} \tag{2}$$

where:

$$mean(x) = \frac{\sum_{i=1}^{n} x_i}{n}$$

$$sd(x) = \frac{\sum_{i=1}^{n}(x_i - mean(x))^2}{n-1}$$

3.1. PCA

PCA allows you to reduce the number of variables in your data set, simplifying data analysis and visualization without losing important information. With PCA, you can identify and remove interdependent variables that are redundant and do not add additional value to your analysis. This method creates new, independent variables, called principal components, which are linear combinations of the original variables. This is a technique commonly used in

exploratory data analysis. It is used in many fields(Osborne, 2014a, 2014b; Tsoulfidis, Athanasiadis, 2022; Watkins, 2018).

The application of PCA is a multi-step process.

- Step1. Standardize the range of continuous initial variables.
- Step 2. Compute the covariance matrix to identify correlations.
- Step 3. Compute the eigenvectors and eigenvalues of the covariance matrix to identify the principal components.
- Step 4. Create a feature vector to decide which principal components to keep.
- Step 5. Recast the data along the principal component's axes.

There are two statistical measures to assess the factor ability of the data: Kaiser-Meyer-Olkin (KMO) and Bartlett's test of Sphericity. Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy KMO test is a measure that has been intended to measure the suitability of data for factor analysis. The KMO values between 0.8 to 1.0 indicate the sampling is adequate. KMO values between 0.7 to 0.79 are middling and values between 0.6 to 0.69 are mediocre. KMO values less than 0.6 indicate the sampling is not adequate and the remedial action should be taken. If the value is less than 0.5, the results of the factor analysis undoubtedly won't be very suitable for the analysis of the data. Bartlett's Test of Sphericity Bartlett's Test of Sphericity tests the variables are orthogonal. A p-value of < 0.05 indicates that factor analysis can be performed on the data.

3.2. Hierarchical Clustering Analysis

Hierarchical grouping is performed to identify natural groups. Groups are formed based on the similarity between data points. The most common method is to perform the clustering method using the Ward method, which minimizes the variance in each cluster (group). It is important to use an appropriate metric to determine the distance between points. For the distance measure, the standard Euclidean distance is used.

A dendrogram is a key tool for interpreting and visualizing the data structure in the context of clustering. It displays the cluster layout as a nested grouping of objects. It starts with a single cluster with only one object, showing how the clusters connect to each other step by step. Horizontal lines or branches illustrate relationships between or distances between clusters. The height of these lines reflects the difference, the distance between the clusters. A dendrogram is designed to help you understand the relationships between clusters (Gan et al., 2007).

3.3. K-means clustering

K-mean is a cluster analysis method that divides a dataset into (K) groups, clusters. Each data point is assigned to the cluster with the closest centroid. A centroid is a point that is the average of the values of points in a set. This method is one of the most popular clustering methods in machine learning(Gan et al., 2007; Morissette, Chartier, 2013).

The precedent of algorithm is as follows:

- Step 1. Randomly assign K objects from the dataset as cluster centres.
- Step 2. (Reassign) Assign each object to which object is most similar based upon mean values.
- Step 3. Update Cluster means, i.e., recalculate the mean of each cluster with the updated values.
- Step 4. Repeat Step 2 until no change occurs.

3.4. Tools for calculations

IT tools are crucial to carry out analyses and present results, whether in a tabular or graphical version. The R programming language was used to perform analyses and graphs. Additionally, libraries such as eurostat, tidyverse, ggrepel, fpc, ggpolt2, DataExplorer, FactoMineR, factoextra were used.

4. Results and discussion

After downloading data from the Eurostat database using the "*eurostat*" library, cities and variables describing the areas were selected. Due to the presentation of the values of the variables in the Likert scale, the weighted values of the variable were determined according to the weights presented in Table 1. These values were then standardised according to formula (1) and an average value was determined for each criterion. Then, each of the criteria was standardized according to formula (2) using R language procedures.

To assess the suitability of the data for factor analysis, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was calculated. The KMO value obtained was 0.83. This suggests that the data is adequate for factor analysis.

Based on the given Measures of Sampling Adequacy (MSA) for each item, here's the interpretation for each variable: ECO (0.76), ENV (0.84), GOV (0.81), HUC (0.86), QLI (0.77), SCI (0.89), TRP (0.87). Overall, all your variables show adequate to excellent sampling adequacy for factor analysis, with MSA values well above the minimum threshold.

Bartlett's Test of Sphericity was performed to examine whether the correlation matrix is an identity matrix, suggesting that the variables are unrelated and unsuitable for structure detection. The test was significant, (χ^2 (21) = 298.94, p < .001), indicating that the variables do indeed share common factors and are suitable for factor analysis. This result supports the appropriateness of proceeding with such an analysis.

The correlation coefficients between the individual criteria were determined, the results are presented in Figure 1.

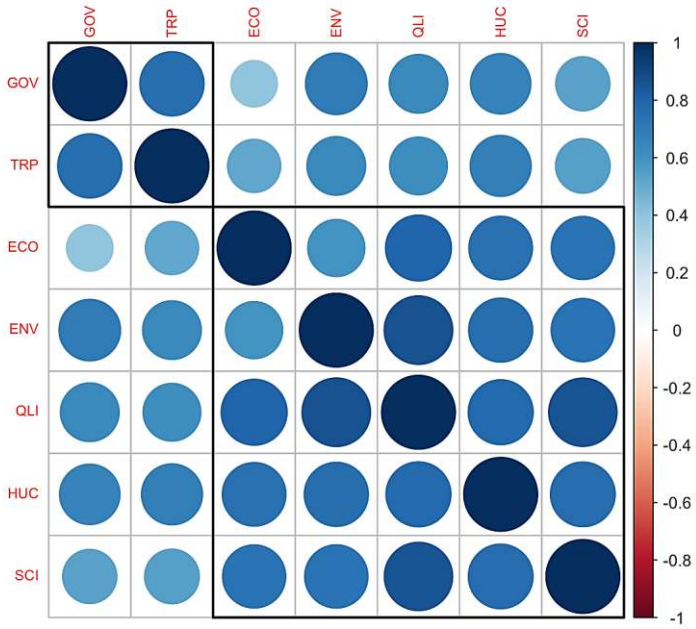

Figure 1. Criteria and correlation coefficients between them grouped hierarchically with two groups selected.

Source: own elaboration.

A scree diagram was made (Figure 2) to determine the number of dimensions used in the analysis. As you can see in the graph, the number of dimensions that will explain more than 90% of the variance is three. Two dimensions explain 86.3% of the variance.

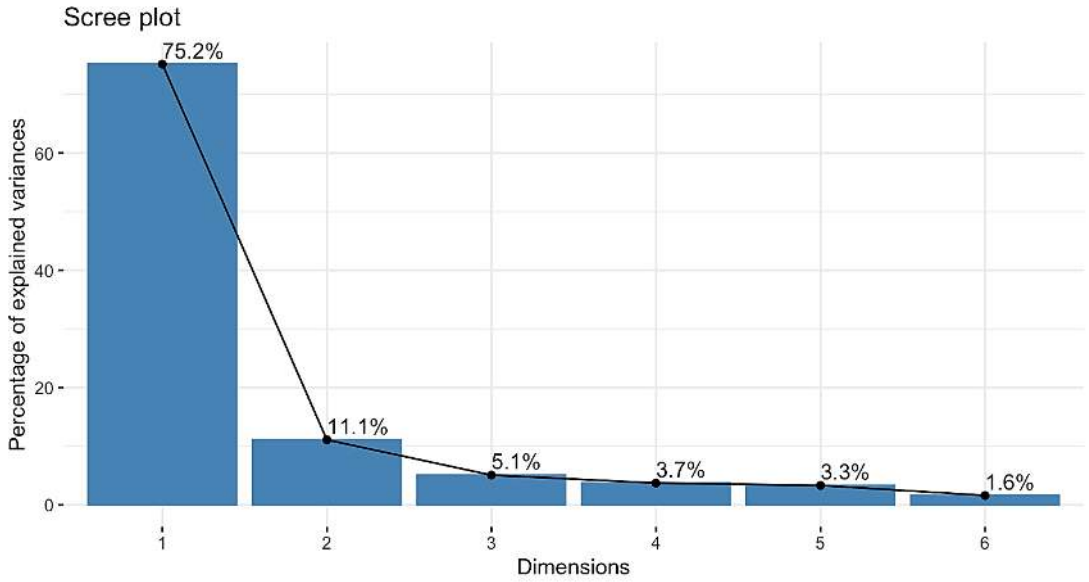

Figure 2. Scree plot - FactoMineR library.

Source: own elaboration.

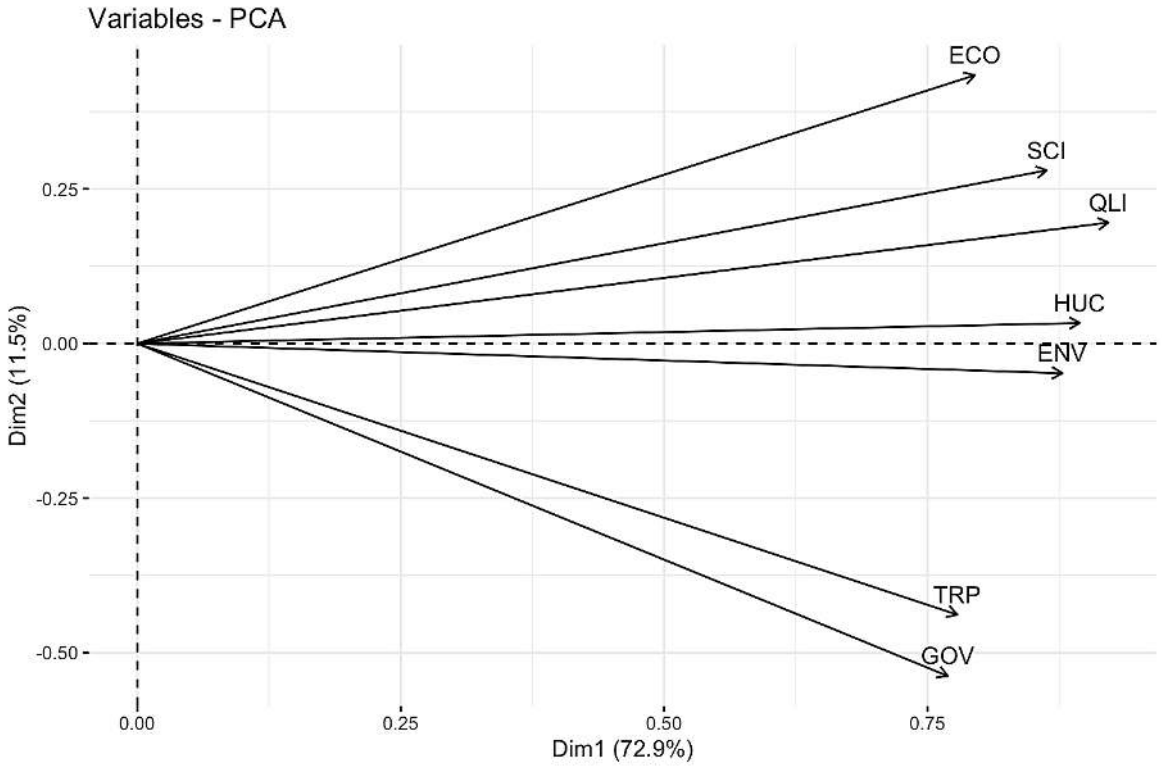

Figure 3. The criteria for the two most important dimensions.

Source: own elaboration.

The relative position of the criteria relative to the two dimensions is shown in Figure 3. The first component, in the light of the questions asked, concerns those elements that relate to matters that you can influence and are close. The second component is matters that you have little influence on, and you can't solve problems easily. The first component can be identified with the quality of one's own life, the second with the quality of management in the city.

A dendogram was performed to confirm the results obtained (Figure 4). At least tree groups of similar cities were marked.

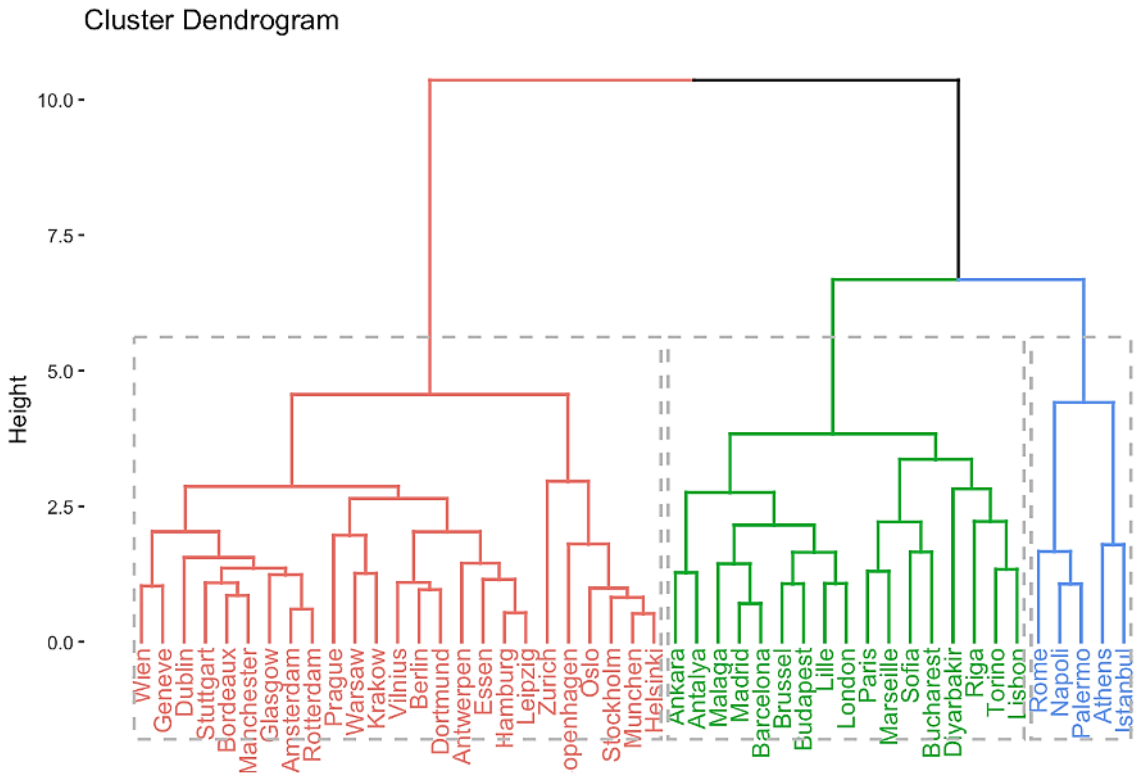

Figure 4. Dendogram with marked groups.

Source: own elaboration.

It was established that three groups of similar cities could be designated. Using the k-means method, cities were assigned to 3 groups. Below, Figure 5 compares the position of cities in relation to two dimensions obtained from PCA. The best city in the PCA assessment in terms of the first component relating to the assessment of the quality of one's own life. In this aspect, Zurich is undoubtedly the best rated by its residents. On the contrary, cities such as Athens, Istanbul and the Italian cities of Palermo, Napoli and Rome are in contrast. The assessment of the city managers shows that the Italian cities of Palermo and Rome are rated the worst. It is puzzling that Turkish cities are the best rated in this respect.

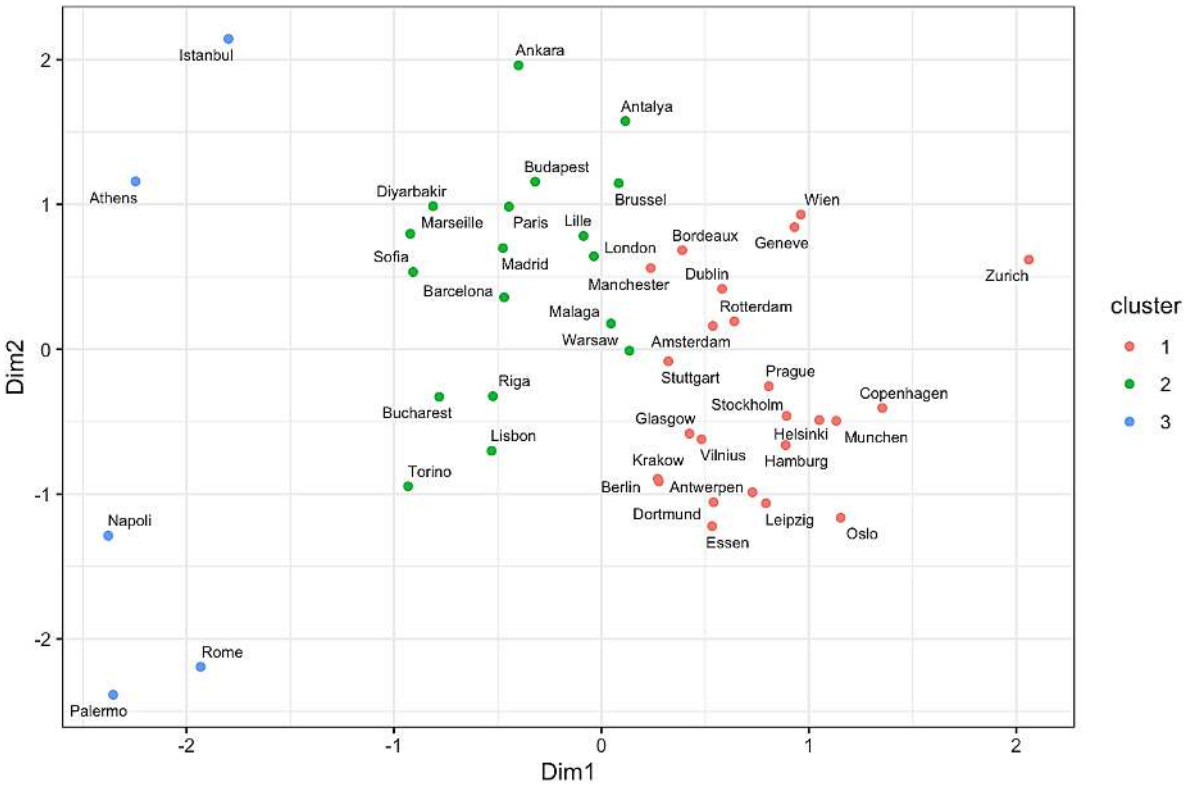

Figure 5. PCA and K-men Combination.

Source: own elaboration.

5. Conclusion

On the basis of the presented analyses concerning large cities in the light of the opinions of their inhabitants, three clearly outlined clusters can be noticed. The first one includes cities such as Zurich, Copenhagen, Munchen, Oslo, Wien. On the opposite side we have Athens, Neapoli, Palermo, Istanbul. Especially the third group clearly stands out from the others. It would be worthwhile to deepen the analysis and add objective indicators to it, such as the income of residents, costs of living, living conditions, etc.

References

1. Akande, A., Cabral, P., Gomes, P., Casteleyn, S. (2019). The Lisbon ranking for smart sustainable cities in Europe. *Sustainable Cities and Society, 44*, pp. 475-487. Retrieved from: https://doi.org/10.1016/j.scs.2018.10.009.
2. Berger, R. (2019). *Smart city strategy index: Vienna and London leading in worldwide ranking.* Retrieved from: https://www.rolandberger.com/publications/publication_pdf/roland_berger_smart_city_breakaway_1.pdf.
3. Cohen, B. (2015). *The 3 Generations of Smart Cities Inside the Development of the Technology Driven City*. Retrieved from: https://www.fastcompany.com/3047795/the-3-generations-of-smart-cities.
4. Giffinger, R., Gudrun, H. (2010). Smart cities ranking: an effective instrument for the positioning of the cities? *ACE: Architecture, City and Environment, 4(12)*, pp. 7-26. Retrieved from: https://doi.org/10.5821/ace.v4i12.2483.
5. Jonek-Kowalska, I. (ed.) (2019). *Wyzwania i uwarunkowania zarządzania inteligentnymi miastami*. Gliwice: Wydawnictwo Politechniki Śląskiej. Retrieved from: https://www.researchgate.net/publication/340298206.
6. Kaiser, Z.R.M.A. (2024). Smart governance for smart cities and nations. *Journal of Economy and Technology, 2*, pp. 216-234. Retrieved from: https://doi.org/10.1016/j.ject.2024.07.003.
7. Kinelski, G. (2022). Smart City 4.0 as a set of social synergies. *Polish Journal of Management Studies, 26(1)*, pp. 92-106. Retrieved from: https://doi.org/10.17512/pjms.2022.26.1.06.
8. Kozak, A. (2022). The Role of Smart Cities during the COVID-19 Pandemic – the Example of New York City. *Biblioteka Regionalisty, 22*, pp. 23-33. Retrieved from: https://doi.org/10.15611/br.2022.1.03.
9. Kuzior, A. (2024). Smart City Conceptual Framework in the Context of Achieving Sustainable Development Goals. *Management Systems in Production Engineering, 32(2)*, pp. 156-161. Retrieved from: https://doi.org/10.2478/mspe-2024-0015.
10. Lai, C.M.T., Cole, A. (2023). Measuring progress of smart cities: Indexing the smart city indices. *Urban Governance, 3(1)*, pp. 45-57. Retrieved from: https://doi.org/10.1016/j.ugj.2022.11.004.
11. Marchlewska-Patyk, K. (2023.). Ewolucja koncepcji smart city jako wyznacznik rozwoju współczesnych miast-polska perspektywa. *Akademia Zarządzania, 7(1)*. Retrieved from: https://doi.org/10.24427/az-2023-0009.
12. Pangsy-Kania, S., Kania, K. (2024). Key Dimensions in Smart Cities' Rankings - Towards Enhancing the Quality of Life for Smart Cities' Inhabitants. *Ekonomia i Prawo, 23(3)*, pp. 493-518. Retrieved from: https://doi.org/10.12775/EiP.2024.025.

13. *Report on the quality of life in European cities* (2023). Retrieved from: https://doi.org/10.2776/182815.
14. Svítek, M., Skobelev, P., Kozhevnikov, S. (2020). *Smart City 5.0 as an Urban Ecosystem of Smart Services* (pp. 426-438). Retrieved from: https://doi.org/10.1007/978-3-030-27477-1_33.
15. Toh, C.K. (2022). Smart city indexes, criteria, indicators and rankings: An in-depth investigation and analysis. *IET Smart Cities, 4(3*), pp. 211-228. Retrieved from: https://doi.org/10.1049/smc2.12036.
16. Vanli, T. (2024). Ranking of Global Smart Cities Using Dynamic Factor Analysis. *Social Indicators Research, 171(2)*, pp. 405-437. Retrieved from: https://doi.org/10.1007/s11205-023-03259-7.
17. Warszawski, U., Mikucki, J. (2021) Koncepcja smart city a COVID-19. Wykorzystanie nowych mediów w obliczu pandemii. *Media Biznes Kultura, Vol. 2, Iss. 11*, pp. 75 -95.

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RANKING OF EUROPEAN CAPITALS BEFORE AND AFTER THE COVID PANDEMIC

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Purpose: The COVID-19 pandemic has introduced the population living in the cities to a new reality. The study aims to show how the perception of the inhabitants of European capitals and their cities has changed during this period.
Design/methodology/approach: Eurostat provides data from the Perception Survey on the Quality of Life in European Cities. The research is carried out every four years. The last two, 2019 and 2023, coincide with the COVID-19 pandemic. A Smart Index was built for 30 European capitals based on selected indicators from the database. The index is based on 34 indicators assigned to seven categories. On this basis, the differences in the assessment of cities before and after the pandemic were shown.
Findings: When comparing the indices of capitals, 11 recorded a decrease in ranking, 13 improved their position, and six remained unchanged.
Research limitations/implications: The study may be supplemented with objective factors in the future. However, it is based on residents' subjective assessments. It is difficult to assess the direct impact of the pandemic on residents' perceptions of the city, especially since the cyclical survey does not include questions related to the pandemic in the questionnaire.
Social implications: The study shows how the perception of key European cities has changed before and after the COVID-19 pandemic. It revealed which aspect of the town's assessment, according to the Smart City methodology, showed improvements and which showed declines. For the managers of these cities, this is an alarming signal indicating which aspects of development require their utmost attention.
Originality/value: The article proposes a Smart City Index based on residents' ratings for European capitals. To compare results from the two periods, a method of unification, considering the values from both periods, was proposed.
Keywords: Smart City Index, Eurostat, COVID-19.
Category of the paper: Research paper.

1. Introduction

In 2023, the degree of urbanisation worldwide was 57 percent. North America, Latin America, and the Caribbean had the highest level of urbanisation, about 83 percent. Next was Europe, with 75 percent. North America is the most urbanised continent, but Tokyo-Yokohama in Japan was the largest urban area in the world that year, with 37.7 million inhabitants.

The urbanisation process means that cities will play a key role in the development of humanity. One of the strategic goals of urban development is to ensure security and prevent situations that create a state of danger or crisis. The concept of Smart City is constantly being developed. We can distinguish five generations of development of this concept (Cohen, 2015; Svítek et al., 2020; Kinelski, 2022; Kuzior, 2024):

- Smart City 1.0 – the ICT sector offers its products for cities.
- Smart City 2.0 – cities are the initiators of ICT implementation.
- Smart City 3.0 – city residents take over the initiative to implement ICT solutions.
- Smart City 4.0 – the sharing of knowledge about modern technologies ensures sustainable development of urban areas and their inhabitants.
- Smart City 5.0 – a multi-agent ecosystem of smart services allows for a harmonious balance of various aspects of residents' lives.

The diversity of the approach to a Smart City has allowed us to understand the dimensions of a Smart City table 1.

Table 1.
Dimension of Smart Cities

Dimension	Description
Government	Interaction between the city authorities and all stakeholders – citizens, entrepreneurs, civil society organisations
Economy	Actions aimed at transforming and strengthening the city's economy
Environment	Environmental management to improve living standards and reduce civilisation pollution
Living	Improving quality of life, social and digital exclusion, safety and care
Mobility	Urban transport services, improving the flow of people, goods and services in the city
People	Appropriate forms of education, career opportunities in labour markets

Source: (Cohen, 2015; Giffinger, Gudrun, 2010; Marchlewska-Patyk).

Table 2.
Smart Cities Index

Selected Smart City Index	Number of cities	1st	2nd	3rd
Cities in Motion Index	74	London	New York	Paris
Global E-Governance Survey	100	Seoul	Madrid	Yerevan
Innovation Cities Index	500	Tokyo	Boston	New York
Smart City Governments	235	Singapore	Seoul	London
Smart Cities Index	500	Oslo	Bergen	Amsterdam
Smart City Index	118	Singapore	Zurich	Oslo

Source: Own research based on (Lai, Cole, 2023).

In addition to the presented list, there are other rankings (Akande et al., 2019; Pangsy-Kania, Kania, 2024; Roland Berger, 2019; Toh, 2022; Vanli, 2024).

The COVID-19 pandemic swept the world from 2019 to 2023. The population living in cities was most exposed to it (Kozak, 2022; Warszawski, Mikucki, n.d.)The study aims to show how the perceptions of the inhabitants of European capitals and their cities have changed over this period.

2. Data structure

The Perception Survey on the Quality of Life in European Cities. was conducted in 79 European cities. It covered all capitals of the countries studied (except Switzerland) and one to six additional cities in larger countries. About 500 residents were interviewed in each city, and 835 interviews were collected in each city. Targets were set at a minimum of 100 online interviews per city and a maximum of 735 via telephone. In some cities, more online interviews were collected.

The availability of data in terms of cities and questions was compared. The following capitals were received: Amsterdam, Ankara, Athens, Berlin, Bratislava, Brussels, Bucharest, Budapest, Copenhagen, Dublin, Lisbon, Ljubljana, London, Luxembourg, Madrid, Nicosia, Oslo, Paris, Prague, Reykjavik, Riga, Rome, Sofia, Stockholm, Tallinn, Valletta, Vienna, Vilnius, Warsaw, Zagreb. Not all capitals can be considered strictly European, but it was decided that they should be left in the study due to their membership in the EU or NATO community.

Due to the specificity of the available data, new areas of city assessment have been defined.

- **ECONOMY** (ECO) – questions about work, real estate prices, the financial and material situation of the household.
- **ENVIRONMENT** (ENV) – assessments of green space, noise and air quality.
- **GOVERNANCE** (GOV) – assessment of satisfaction with solving local problems, procedures applied by the city authorities, information and administrative services, corruption of local authorities.
- **HUMAN CAPITAL** (HUC) – sports and cultural activities as well as facilities offered by the city, education.
- **QUALITY OF LIFE** (QLI) – trust in other residents, satisfaction with life in the city, assessment of the city as a place to live.
- **SOCIAL COHESION INDICATORS** (SCI) – health care, safety, friendliness towards immigrants, minorities, LGBT communities, non-material help.
- **TRANSPORT** (TRN) – diverse evaluation of urban transport.

Based on the Eurostat database, the following set of indicators is proposed in Table 3.

Table 3.
Indicators for the assessment of cities

ID	Questions with answer variants and weights
ECO_01	In this city, it is easy to find a good job: strongly agree; somewhat agree; somewhat disagree; strongly disagree; don't know / no answer: [2, 1, -1, -2, 0]
ECO_02	In this city, it is easy to find good housing at a reasonable price: strongly agree; somewhat agree; somewhat disagree; strongly disagree; don't know / no answer: [2, 1, -1, -2, 0]
ECO_03	The financial situation of your household: very satisfied; fairly satisfied; not very satisfied; not at all satisfied; don't know / no answer: [2, 1, -1, -2, 0]
ECO_04	If you needed material help (e.g. money, a loan or an object), you could receive it from relatives, friends, neighbours or other persons you know: yes; no; don't know / no answer / refuses: [1, 0, 0]
ENV_01	Green spaces such as public parks or gardens: very satisfied; rather satisfied; rather unsatisfied; not at all satisfied; don't know / no answer: [2, 1, -1, -2, 0]
ENV_02	The quality of the air in the city: very satisfied; rather satisfied; rather unsatisfied; not at all satisfied; don't know / no answer: [2, 1, -1, -2, 0]
ENV_03	The noise level in the city: very satisfied; rather satisfied; rather unsatisfied; not at all satisfied; don't know / no answer: [2, 1, -1, -2, 0]
GOV_01	I am satisfied with the amount of time it takes to get a request solved by my local public administration: strongly agree; somewhat agree; somewhat disagree; strongly disagree; don't know / no answer / refuses: [2, 1, -1, -2, 0]
GOV_02	The procedures used by my local public administration are straightforward and easy to understand: strongly agree, somewhat agree; somewhat disagree, strongly disagree; don't know / no answer / refuses: [2, 1, -1, -2, 0]
GOV_03	Information and services of my local public administration can be easily accessed online: strongly agree; somewhat agree; somewhat disagree; strongly disagree; don't know / no answer / refuses: [2, 1, -1, -2, 0]
GOV_04	There is corruption in my local public administration: strongly agree; somewhat agree; somewhat disagree; strongly disagree; don't know / no answer / refuses: [-2, -1, 1, 2, 0]
HUC_01	Sports facilities such as sports fields and indoor sports halls in the city: very satisfied; rather satisfied; rather unsatisfied; not at all satisfied; don't know / no answer: [2, 1, -1, -2, 0]
HUC_02	Cultural facilities such as concert halls, theatres, museums and libraries in the city: very satisfied; rather satisfied; rather unsatisfied; not at all satisfied; don't know / no answer: [2, 1, -1, -2, 0]
HUC_03	Schools and other educational facilities: very satisfied; rather satisfied; rather unsatisfied; very unsatisfied; don't know / no answer / refuses: [2, 1, -1, -2, 0]
QLI_01	Generally speaking, most people in this city can be trusted: strongly agree, somewhat agree, somewhat disagree, strongly disagree; don't know / no answer: [2, 1, -1, -2, 0]
QLI_02	Most people in my neighbourhood can be trusted: strongly agree, somewhat agree; somewhat disagree, strongly disagree; don't know / no answer: [2, 1, -1, -2, 0]
QLI_03	I'm satisfied to live in this city: strongly agree; somewhat agree; somewhat disagree; strongly disagree; don't know / no answer: [2, 1, -1, -2, 0]
QLI_04	The neighbourhood where you live: very satisfied; fairly satisfied; not very satisfied; not at all satisfied; don't know / no answer: [2, 1, -1, -2, 0]
QLI_05	For people in general: a good place to live; not a good place to live; don’t know/no answer/refuses: [2, 1, 0]
SCI_01	Health care services, doctors and hospitals: very satisfied; rather satisfied; rather unsatisfied; very unsatisfied; don't know / no answer / refuses: [2, 1, -1, -2, 0]
SCI_02	I feel safe walking alone at night in my city: strongly agree; somewhat agree; somewhat disagree; strongly disagree; don't know / no answer / refuses: [2, 1, -1, -2, 0]
SCI_03	I feel safe walking alone at night in my neighbourhood: strongly agree; somewhat agree; somewhat disagree; strongly disagree; don't know / no answer / refuses: [2, 1, -1, -2, 0]
SCI_03	For racial and ethnic minorities: a good place to live; not a good place to live; don’t know/no answer/refuses: [-1, -2, 0]
SCI_04	For gay or lesbian people: a good place to live; not a good place to live; don’t know/no answer/refuses: [2, 1, 0]
SCI_05	For immigrants from other countries: a good place to live; not a good place to live; don’t know/no answer/refuses: [-1, -2, 0]
SCI_07	For young families with children: a good place to live; not a good place to live; don’t know/no answer/refuses: [2, -2, 0]

Cont. table 3.

SCI_08	For elderly people: a good place to live; not a good place to live; don't know/no answer/refuses: [2, -2, 0]
SCI_06	Confidence in the local police force: yes; no; don't know / no answer / refuses: [1, 0, 0]
SCI_07	Money or property stolen from you or another household member in your city the last 12 months: yes; no; don't know / no answer / refuses: [0, 1, 0]
SCI_08	Being assaulted or mugged in your city the last 12 months: yes; no; don't know / no answer / refuses: [0, 1, 0]
SCI_09	If you needed non material help (e.g. somebody to talk to, help with doing something or collecting something), you could receive it from relatives, friends, neighbours or other persons you know: yes; no; don't know / no answer / refuses: [1, 0, 0]
TRP_01	Public transport in the city, for example, bus, tram or metro: very satisfied; rather satisfied; rather unsatisfied; not at all satisfied; don't know / no answer: [2, 1, -1, -2, 0]
TRP_02	Means of transport most often used : car; motorcycle; bicycle; foot; train; **urban public transport**; other; do not commute; don't know / no answer / refuses : [0,0,0,0,0,**1**,0,0,0]
TRP_03	Public transport affordable: strongly agree; somewhat agree; somewhat disagree; strongly disagree; don't know / no answer / refuses: [2, 1, -1, -2, 0]
TRP_04	Public transport safe: strongly agree; somewhat agree; somewhat disagree; strongly disagree; don't know / no answer / refuses: [2, 1, -1, -2, 0]
TRP_05	Public transport easy to get: strongly agree; somewhat agree; somewhat disagree; strongly disagree; don't know / no answer / refuses: [2, 1, -1, -2, 0]

Source: own elaboration.

3. Methods

The answers to the questions are predominantly on a 5-point Likert scale. Each question is accompanied by the weights applied to each answer. The database shows the percentage of citizens choosing individual categories. Weighted answers to each question were determined, thus obtaining the indicator's value. The scales have been selected so that a larger value of the indicator shows the greater importance of the indicator.

Then, the obtained values were normalised using a formula that considered the worst and best assessments in each of the studied periods.

The formula used is min-max normalisation:

$$score(x_i) = (100 - 50)\frac{x_i - \min\limits_{k\in\{i,j\}}(x_k)}{\max\limits_{k\in\{i,j\}}(x_k) - \min\limits_{k\in\{i,j\}}(x_k)} + 50 \quad (1)$$

where:

i – index for 2019 data,

j – indexes for 2023 data.

After normalisation, the average value of the indicators was determined for each criterion, and the final ranking was obtained as the sum of the city's ranking for each requirement.

The final score was determined by calculating the sum of all the indicator's weighted average scores. Below is a detailed description of each factor within the study and the source used.

4. Results and discussion

After the calculations have been carried out following the proposed procedure. The following final results were obtained, showing the ranks for each criterion and the city's final ranking (Figure 1, Table 4, Table 5)

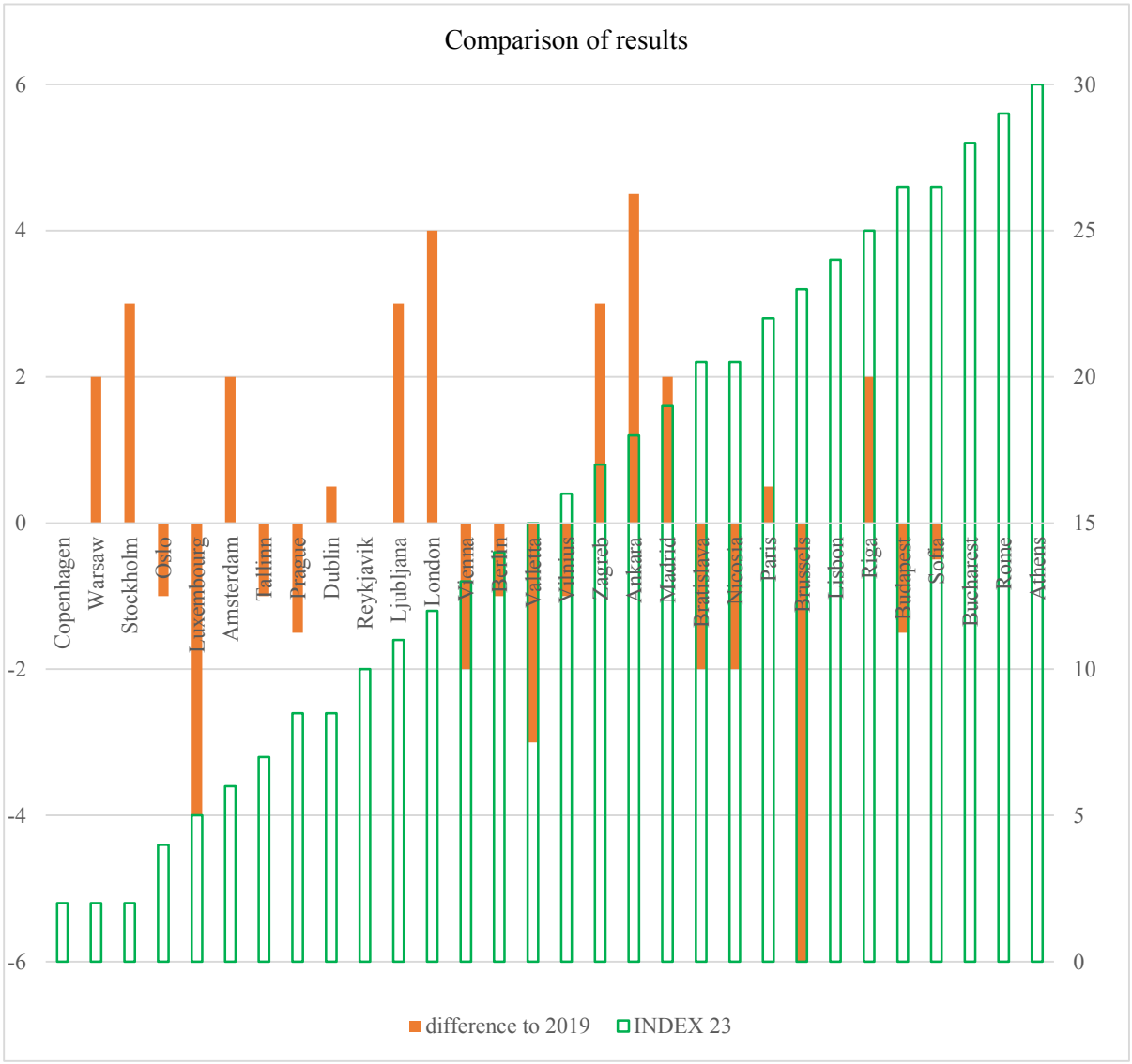

Figure 1. Comparison of INDEX 23 results and difference compared to 2019 results.

Source: own research.

Table 4.
Indicators for the assessment of cities – year 2019

Capitol	ECO	ENV	GOV	HUC	QLI	SCI	TRP	INDEX 19
Amsterdam	12	13	8	4	12	7	14	8
Ankara	24	15	3	27	21	26	24	22,5
Athens	30	30	28	30	30	30	27	30
Berlin	10	11	25	17	11	10	11	13
Bratislava	13	20	18	22	20	18	12	18,5
Brussels	26	19	6	14	18	19	18	17
Bucharest	8	29	23	29	27	24	21	28
Budapest	27	22	10	23	25	25	15	25
Copenhagen	3	8	2	9	1	4	9	2
Dublin	15	1	7	6	6	20	23	9
Valletta	7	28	4	24	8	3	17	12
Nicosia	20	18	9	15	16	16	29	18,5
Lisbon	29	21	27	18	15	8	26	24
Ljubljana	18	7	17	3	23	17	20	14
London	19	14	13	16	19	21	13	16
Luxembourg	16	2	1	2	5	1	2	1
Madrid	28	24	20	25	13	13	8	21
Oslo	2	3	19	8	2	2	5	3
Paris	23	25	11	12	24	23	22	22,5
Prague	1	16	21	5	14	9	1	7
Reykjavik	17	4	22	1	3	5	28	10
Riga	22	12	26	20	26	28	25	27
Rome	25	27	30	28	29	27	30	29
Sofia	6	26	24	26	28	29	16	26
Stockholm	9	6	15	10	4	6	7	5
Tallinn	5	10	14	11	9	12	4	6
Vienna	4	9	12	19	10	15	19	11
Vilnius	11	23	16	13	22	22	6	15
Warsaw	14	5	5	7	7	11	3	4
Zagreb	21	17	29	21	17	14	10	20

Source: Own research.

The most significant drop in the ranking is in Brussels; it fell by six places, then a substantial drop by four places was recorded by Luxembourg, which lost the first place in 2019. Surprisingly, Ankara, London, and Stockholm are the capitals that have gained the most. London, with the beginnings of the Brexit crisis; and Stockholm, with a completely different policy of restrictions against the COVID pandemic, have gained the most in the eyes of their citizens.

Table 5.
Indicators for the assessment of cities – year 2023

Capitol	ECO	ENV	GOV	HUC	QLI	SCI	TRP	INDEX 23
Amsterdam	12	13	8	4	10	4	14	6
Ankara	20	16	4	25	17	25	19	18
Athens	29	30	28	30	30	30	27	30
Berlin	15	15	26	17	9	10	11	14
Bratislava	9	21	21	23	20	19	20	20,5
Brussels	26	19	5	18	23	24	23	23
Bucharest	14	29	27	29	28	23	24	28
Budapest	27	23	12	22	25	26	22	26,5
Copenhagen	4	8	1	10	2	5	12	2
Dublin	17	1	6	5	6	15	21	8,5
Valletta	11	28	7	24	12	7	17	15
Nicosia	21	18	10	16	22	17	29	20,5
Lisbon	28	22	24	21	18	8	26	24
Ljubljana	13	7	15	3	14	16	16	11
London	19	11	9	13	11	12	10	12
Luxembourg	23	3	2	7	7	6	4	5
Madrid	24	25	17	28	15	14	9	19
Oslo	2	5	20	8	1	1	6	4
Paris	30	24	11	14	24	18	15	22
Prague	1	17	19	2	19	11	2	8,5
Reykjavik	8	6	22	1	4	3	28	10
Riga	22	12	23	19	26	29	25	25
Rome	25	26	30	26	29	27	30	29
Sofia	10	27	25	27	27	28	13	26,5
Stockholm	5	4	14	11	3	2	3	2
Tallinn	6	9	13	9	8	20	5	7
Vienna	3	10	16	20	13	21	18	13
Vilnius	7	20	18	12	21	22	8	16
Warsaw	16	2	3	6	5	9	1	2
Zagreb	18	14	29	15	16	13	7	17

Source: Own research.

The results obtained for the four best capitals in the ranking and the two worst were compared on radar charts (Figure 2).

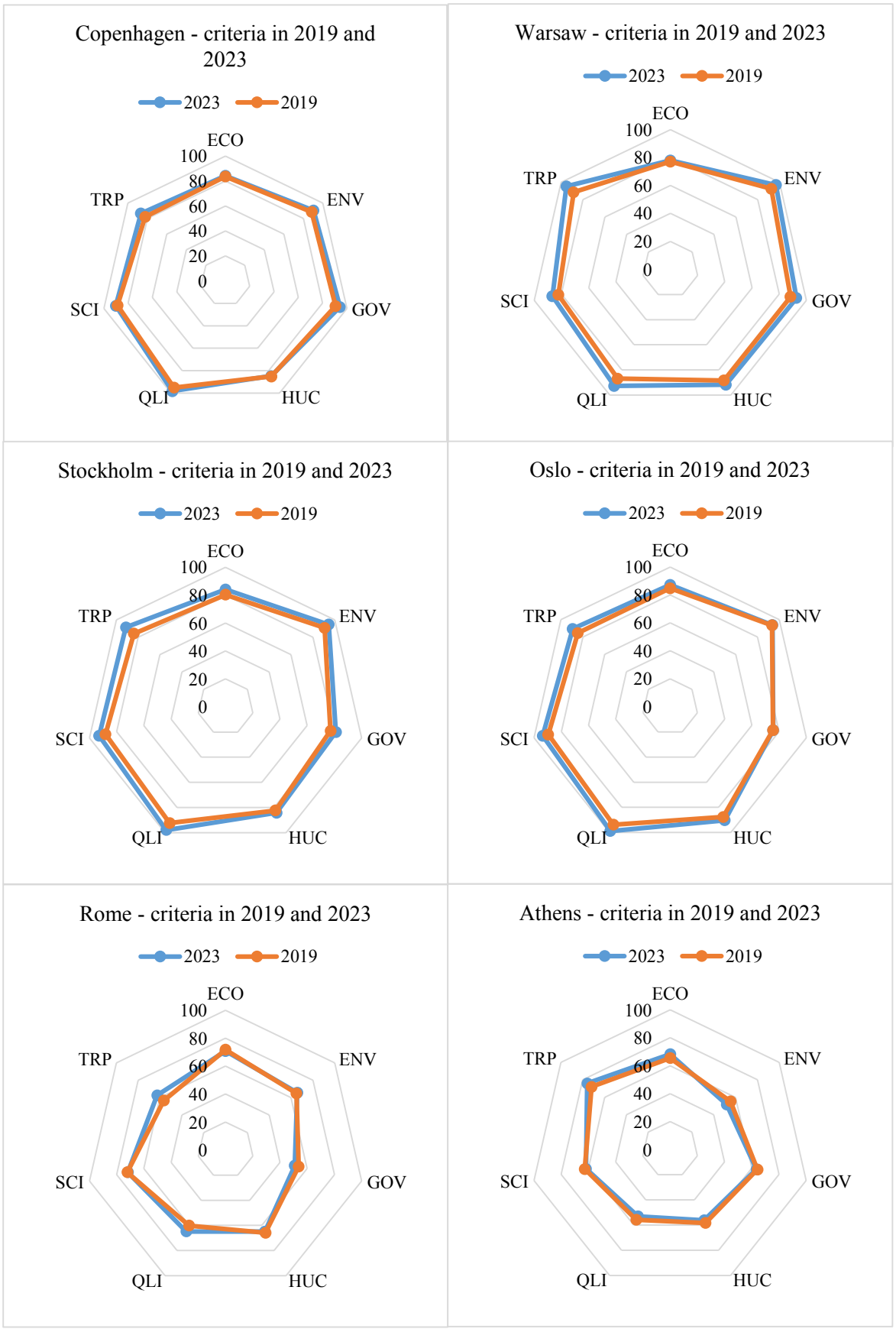

Figure 2. Radar chart for four of the best capitols and two of the worst.

Source: own research.

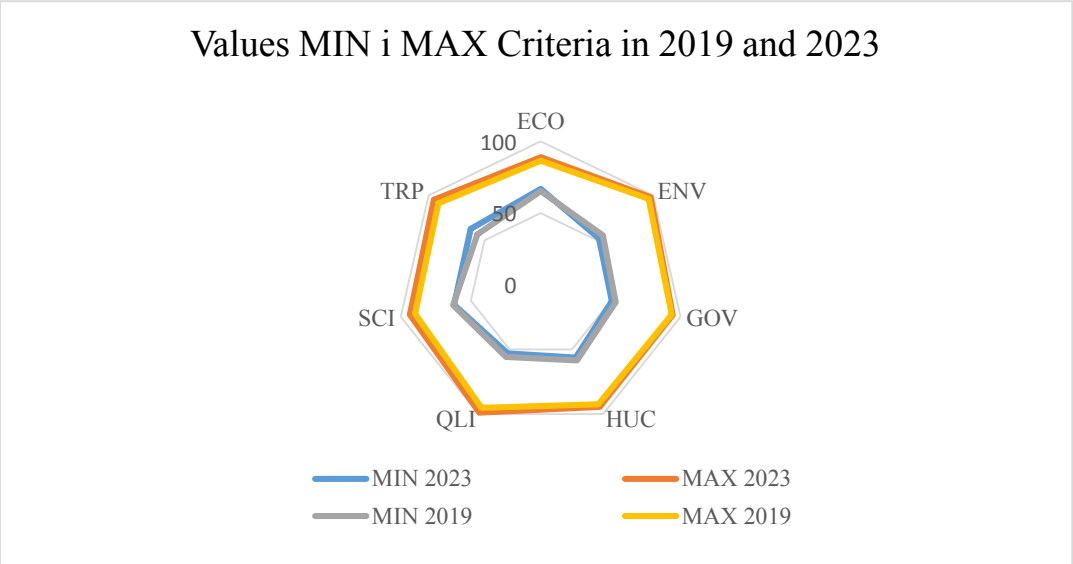

Figure 3. Radar chart – min and max values in the year for the proposed criteria.

Source: own research.

Comparing the maximum values for the obtained values of the criterion before the rank is determined, no significant differences in the values concerning the years can be seen. However, these values deviate from the assumed minimum and maximum values for individual criteria. The most significant deviations from the values for max 100 and min 50 are for the economic criterion. This is influenced by two questions, ECO_1 and ECO_2, which are negatively correlated. The more we earn, the prices of apartments rise, and it is more difficult to buy an apartment reasonably priced.

Table 6

Kruskal-Wallis rank sum test result

YEAR	STATISTIC	P.VALUE	PARAMETER
2019	12,91	0,04	6
2023	6,23	0,40	6

Source: Own research.

Table 7

Pairwise comparisons using Wilcoxon rank sum exact test p-value

	ECO	ENV	GOV	HUC	QLI	SCI
ENV	0,31	-	-	-	-	-
GOV	0,59	0,59	-	-	-	-
HUC	0,69	0,59	0,96	-	-	-
QLI	0,27	0,93	0,59	0,55	-	-
SCI	0,07	0,93	0,55	0,55	0,84	-
TRP	0,00	0,84	0,27	0,29	0,55	0,59

p-value adjustment method: BH

Source: Own research.

Table 8
Kruskal-Wallis rank sum test result

indic	STATISTIC	P.VALUE	PARAMETER
ECO	0,25	0,62	1
ENV	0,25	0,62	1
GOV	0,52	0,47	1
HUC	0,12	0,73	1
QLI	1,51	0,22	1
SCI	1,77	0,18	1
TRP	8,66	0,00	1

Source: own research.

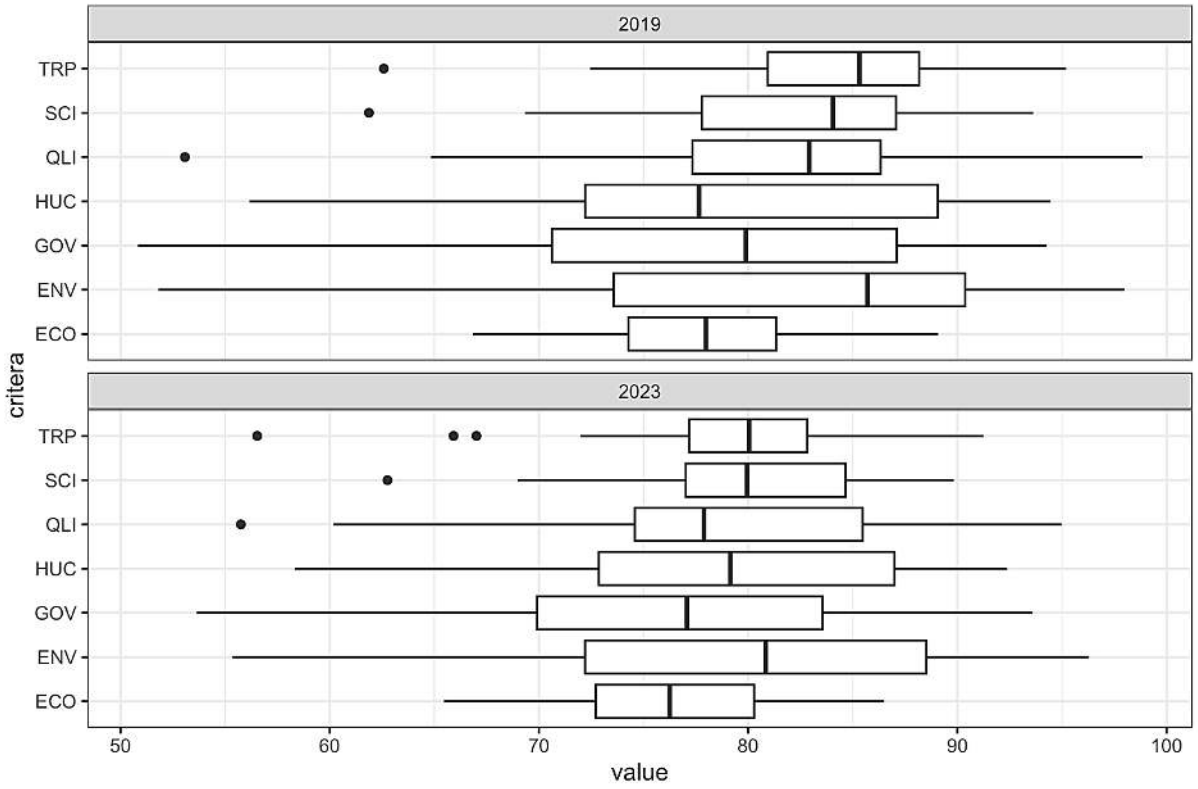

Figure 4. Boxplots for criteria.

Source: own research.

A boxplot has been created for each of the criteria. Boxplot charts show how the distribution of values for individual years is shaped. Analyzing the median values for individual criteria, it can be concluded that, in general, the city ratings in individual categories have decreased.

The data analysis based on the Kruskal-Wallis test shows that the individual categories did not differ in 2013. However, in 2019, there is at least one that is significantly different from the others.

5. Conclusion

As you can see, the most significant drop in the ranking is in Brussels; it fell by six places, then a substantial drop by four places was recorded by Luxembourg, which lost the first place in 2019. Surprisingly, Ankara, London, and Stockholm are the capitals that have gained the most. London, with the beginnings of the Brexit crisis; and Stockholm, with a completely different policy of restrictions against the COVID pandemic, have gained the most in the eyes of their citizens.

The lack of COVID data directly related to cities did not allow to examine the broader associations of the assessment with the pandemic

References

1. Akande, A., Cabral, P., Gomes, P., Casteleyn, S. (2019). The Lisbon ranking for smart, sustainable cities in Europe. *Sustainable Cities and Society, 44*, pp. 475-487. Retrieved from: https://doi.org/10.1016/j.scs.2018.10.009.
2. Berger, R. (2019). *Smart city strategy index: Vienna and London leading in worldwide ranking.* Retrieved from: https://www.rolandberger.com/publications/publication_pdf/roland_berger_smart_city_breakaway_1.pdf.
3. Cohen, B. (2015). *The 3 Generations of Smart Cities Inside the Development of the Technology Driven City*. Retrieved from: https://www.fastcompany.com/3047795/the-3-generations-of-smart-cities.
4. Giffinger, R., Gudrun, H. (2010). Smart Cities Ranking: An effective instrument for the positioning of the cities? *ACE: Architecture, City and Environment, 4(12)*, pp. 7-26. Retrieved from: https://doi.org/10.5821/ace.v4i12.2483.
5. Jonek-Kowalska, I. (ed.) (2019). *Wyzwania i uwarunkowania zarządzania inteligentnymi miastami*. Gliwice: Wydawnictwo Politechniki Śląskiej. Retrieved from: https://www.researchgate.net/publication/340298206.
6. Kaiser, Z.R.M.A. (2024). Smart governance for smart cities and nations. *Journal of Economy and Technology, 2*, *216234*. Retrieved from: https://doi.org/10.1016/j.ject.2024.07.003.
7. Kinelski, G. (2022). Smart City 4.0 as a set of social synergies. *Polish Journal of Management Studies, 26(1)*, pp. 92-106. Retrieved from: https://doi.org/10. 17512/pjms.2022.26.1.06

8. Kozak, A. (2022). The Role of Smart Cities during the COVID-19 Pandemic – the Example of New York City. *Biblioteka Regionalisty, 22*, pp. 23-33. Retrieved from: https://doi.org/10.15611/br.2022.1.03.
9. Kuzior, A. (2024). Smart City Conceptual Framework in the Context of Achieving Sustainable Development Goals. *Management Systems in Production Engineering, 32(2)*, pp. 156-161. Retrieved from: https://doi.org/10.2478/mspe-2024-0015.
10. Lai, C.M.T., Cole, A. (2023). Measuring progress of smart cities: Indexing the smart city indices. *Urban Governance, 3(1)*, pp. 45-57. Retrieved from: https://doi.org/10.1016/j.ugj.2022.11.004.
11. Marchlewska-Patyk, K. (2023). Ewolucja koncepcji smart city jako wyznacznik rozwoju współczesnych miast-polska perspektywa. *Akademia Zarządzania, 7(1)*. Retrieved from: https://doi.org/10.24427/az-2023-0009
12. Pangsy-Kania, S., Kania, K. (2024). Key Dimensions in Smart Cities' Rankings - Towards Enhancing the Quality of Life for Smart Cities' Inhabitants. *Ekonomia i Prawo, 23(3)*, pp. 493-518. Retrieved from: https://doi.org/10.12775/EiP.2024.025.
13. *Report on the quality of life in European cities* (2023). Retrieved from: https://doi.org/10.2776/182815.
14. Svítek, M., Skobelev, P., Kozhevnikov, S. (2020). *Smart City 5.0 as an Urban Ecosystem of Smart Services* (pp. 426-438). Retrieved from: https://doi.org/10.1007/978-3-030-27477-1_33.
15. Toh, C.K. (2022). Smart city indexes, criteria, indicators and rankings: An in-depth investigation and analysis. *IET Smart Cities, 4(3)*, pp. 211-228. Retrieved from: https://doi.org/10.1049/smc2.12036.
16. Vanli, T. (2024). Ranking of Global Smart Cities Using Dynamic Factor Analysis. *Social Indicators Research, 171(2)*, pp. 405-437. Retrieved from: https://doi.org/10.1007/s11205-023-03259-7.
17. Warszawski, U., Mikucki, J. (2021) Koncepcja smart city a COVID-19. Wykorzystanie nowych mediów w obliczu pandemii. *Media Biznes Kultura, Vol. 2, Iss. 11*, pp. 75-95.

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ORGANIZATION AND MANAGEMENT SERIES NO. 213

UNLOCKING THE POTENTIAL OF ARTIFICIAL INTELLIGENCE IN ROJECT MANAGEMENT: INSIGHTS FROM THE POLISH IT SECTOR

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Purpose: This article examines the application and impact of Artificial Intelligence (AI) in Project Management within the IT sector in Poland. It provides insights into how AI tools are utilized in project planning, execution, and decision-making processes, contrasting findings with existing studies predominantly focused on reviewing AI tools rather than their practical implementation. By shifting the focus to real-world usage, this research aims to provide a deeper understanding of how AI is integrated into the daily workflows of IT companies, highlighting both the benefits and challenges faced in applying AI technologies to Project Management.

Design/methodology/approach: The research combines a comprehensive literature review with a multiple-case study approach. Four firms operating in the IT sector in Poland were analyzed: three international companies with substantial market presence in Poland and one small, local enterprise. The study explores their adoption of AI-driven Project Management tools, examining practical implementations and outcomes.

Findings: The study identifies varied adoption levels and applications of AI in Project Management among the selected firms. While international companies showcased advanced AI integration, the local enterprise demonstrated innovative, tailored approaches to address specific challenges. Findings reveal that AI enhances efficiency in resource allocation, risk management, and team collaboration. However, barriers such as cost, employee training, and organizational resistance were noted, particularly in smaller firms. In larger companies, privacy concerns, regulatory requirements, and the necessity for secure data storage and processing significantly limit AI adoption. These organizations must also ensure thorough legal vetting and compliance with Data Protection Agreements (DPAs), adding layers of complexity to the implementation process

Research limitations/implications: The scope is limited to IT companies operating within the Polish market, which may not fully represent trends in other sectors or regions. Future research could expand the sample size and explore cross-industry applications of AI in Project

Management. The findings underscore the need for tailored strategies to overcome challenges in AI adoption, particularly for small and medium-sized enterprises (SMEs).
Practical implications: This paper offers actionable insights for IT companies seeking to implement AI in Project Management. It highlights the importance of organizational readiness, and alignment of AI tools with project objectives. Lessons from international firms and the innovative practices of local enterprises provide a balanced perspective for practitioners and policymakers.
Originality/value: While most of the current literature emphasizes theoretical analyses of AI implementation in Project Management, including discussions on challenges, potential benefits, and conceptual frameworks, this study takes a more practical approach. By conducting interviews and examining real-world applications of AI in four IT firms operating in Poland, the research provides unique insights into the tangible use cases, organizational strategies, and contextual factors shaping AI adoption. This practical orientation offers valuable guidance for practitioners and researchers aiming to bridge the gap between AI assumption and implementation.
Keywords: Artificial Intelligence, Project Management, Project Planning, Tender Phase, Data-driven Decisions.
Category of the paper: Research paper.

1. Introduction

In today's fast-evolving business landscape, achieving agility in Project Management has become essential for organizations aiming to stay competitive. Traditional Project Management methods, such as the waterfall approach, often struggle to adapt to changing requirements and unexpected challenges, resulting in delays and inefficiencies. Agile methodologies have gained prominence as a solution, focusing on iterative development, continuous feedback, and collaborative teamwork to address uncertainty and deliver value incrementally. However, even agile approaches face limitations, particularly in resource management, accurate forecasting, and risk identification, which can impede project success (Zhou et al., 2024).

Artificial Intelligence (AI) has emerged as a game-changer in Project Management, providing tools that help overcome these limitations. AI can automate repetitive tasks, support faster and more informed decision-making, and foster improved collaboration and communication among team members. AI-powered tools analyze project data, forecast outcomes, and propose solutions for potential issues (Weng et al., 2024). Additionally, they learn from past projects, enhancing precision and efficiency in future efforts. Such capabilities enable project managers to allocate resources better, predict risks, and respond to challenges effectively, driving improved performance across project lifecycles (Bi et al., 2024).

However, integrating AI into Project Management also brings challenges, such as ethical concerns and fears of job displacement. Understanding AI's role and impact in Project Management is critical to harnessing its benefits while mitigating potential risks. Furthermore,

while much of the existing research explores AI's theoretical potential—discussing its challenges and benefits—there is a lack of studies examining its practical applications. This gap is particularly evident in less-studied markets like Poland, where the unique organizational, economic, and cultural context may influence AI adoption. The Polish IT sector offers a compelling case for exploring AI in Project Management. Unlike markets such as Australia, where AI-driven Project Management has been more extensively documented (Tan, 2023), the Polish market provides an opportunity to examine real-world applications in a less mature context. Additionally, projects' inherently unique and temporary nature often challenges AI adoption, as the limited availability of project-specific data can hinder AI's effectiveness. These factors highlight the importance of studying AI use in a practical, context-driven manner.

This study aims to fill this research gap by analyzing how AI is applied in Project Management within the Polish IT sector. Using a combination of literature review and case studies involving four firms—three international companies operating in Poland and one smaller, local enterprise—this research examines practical implementations of AI and the challenges faced during its adoption. The findings offer actionable insights into how AI tools can enhance project outcomes, particularly in emerging markets. By investigating AI's role in automating tasks, supporting decision-making, and improving team dynamics, this study provides a detailed understanding of both the opportunities and obstacles in AI adoption. It emphasizes the need for organizations to tailor AI solutions to their specific contexts to realize their potential benefits fully. This research contributes to the growing body of knowledge on AI in Project Management and offers practical guidance for companies and policymakers seeking to leverage AI effectively while addressing its inherent challenges.

2. Literature Review

The incorporation of Artificial Intelligence (AI) into Project Management (PM) has gained considerable attention in recent years, reflecting its growing importance in enhancing agility and efficiency in project execution (Karamthulla, 2024). The literature highlights the transformative potential of AI in PM, particularly in Agile Project Management, by addressing complex challenges and improving project outcomes. This literature review explores the key applications of AI in Agile Project Management, focusing on its innovations, the problems it helps resolve, and the benefits it can offer (Muda, 2023). AI's application in Project Management is an emerging field, as its rapid evolution has led to significant advancements in various domains, including PM. Gil et al. (2021) emphasize the transformative potential of hybrid computational models and machine learning systems in PM, although they note that these technologies are still in their early stages. Their work provides a taxonomy of AI applications in different PM subfields, offering a foundational resource for researchers and

practitioners interested in exploring AI's role in project leadership. Similarly, Victor (2023) underscores the growing adoption of AI in business, pointing out that its impact on PM is still in its nascent phase. Victor suggests that the integration of AI into PM aligns with the theory of evolution, where success depends on adaptability. By analyzing data inputs, AI facilitates more informed decision-making, allowing project managers to navigate uncertainty and predict project outcomes more accurately (Odejide, 2024).

AI's application in PM is not always intuitive due to the unstructured nature of project data compared to more structured fields, as noted by Russell and Norvig (2021). However, the existing literature and AI tools demonstrate their utility in critical areas such as cost estimation, risk assessment, and resource allocation (Lewicka, 2024). For instance, Rankovic et al. (2021) apply artificial neural networks and linear regression to predict project effort based on cost drivers and software size. Similarly, Nayebi et al. (2018) developed a decision-support system using natural language processing to enhance effort estimation and manage change requests. These applications underscore AI's potential to improve PM decision-making by providing more accurate forecasting and insights. Despite these promising advancements, AI's role in PM software has mainly been limited to input-output interactions, rather than directly performing core PM tasks. Chatbots like Stratejos and Redbooth assist project teams with task management and workflow coordination, automating daily project updates.

Meanwhile, tools such as PMOtto and Cloverleaf integrate AI to handle core PM functions. PMOtto provides AI-powered recommendations on time, cost, and resource allocation, while Cloverleaf offers insights into team dynamics, helping project managers optimize team composition and skill development. These applications illustrate AI's potential to improve both the planning and execution phases of projects.

However, despite these advancements, many organizations struggle to fully comprehend the benefits of AI and how to align AI solutions with their specific needs (Rakova, 2021). This gap highlights the need for a structured approach to identify suitable AI applications for organization-specific challenges (Zadeh, 2024). Current research suggests a more tailored methodology is required to help organizations realize AI's full potential in PM. AI also transforms Agile Project Management by automating repetitive tasks, improving decision-making, and optimizing project outcomes (Manchana, 2022). One of the key benefits of AI in Agile Project Management is its ability to automate time-consuming tasks, such as scheduling, resource allocation, and status updates. By automating these routine tasks, AI allows project teams to focus on higher-value activities like strategic planning and problem-solving. AI-powered Project Management tools, for example, can automatically assign tasks based on team members' skills and availability, reducing administrative burdens on project managers (Bi, 2024).

Another important application of AI in Agile Project Management is predictive analytics. AI, fueled by machine learning algorithms, analyzes historical project data to identify patterns and forecast potential risks, resource requirements, and project timelines (Karamthulla, 2024).

These insights assist project managers in making informed decisions about project scope, timelines, and resource allocation, helping to reduce the uncertainty that often characterizes Agile projects. By using predictive analytics, Agile teams can anticipate challenges and proactively take action to mitigate risks. AI also enhances collaboration and communication within Agile teams. AI-powered communication tools can analyze team interactions, identify communication bottlenecks, and suggest improvements to optimize collaboration (Kasaraneni, 2021). Chatbots and virtual assistants also serve as communication hubs, providing team members quick access to project updates, task lists, and other relevant information. This fosters a more collaborative and efficient working environment, ensuring all team members remain aligned and focused on achieving project goals. Moreover, AI significantly enhances real-time monitoring and feedback, vital components of Agile Project Management (Adegbite, 2023). AI tools continuously analyze data from various project sources, providing real-time insights into project progress, task completion, and emerging risks. These tools can flag issues as they arise, enabling project managers and teams to take corrective actions promptly, and ensuring that the project stays on track. Furthermore, AI-driven feedback loops allow for continuous improvement by offering data-driven insights that guide project teams in refining their approaches and strategies over time (Bainey, 2024). This real-time monitoring and feedback ensures that Agile projects align with their objectives.

Integrating AI into Agile Project Management offers many benefits, including the automation of repetitive tasks, predictive insights, enhanced communication, and real-time monitoring. These capabilities allow Agile teams to work more efficiently, adapt to changing conditions, and achieve successful project outcomes (Ciric, 2022).

While the current literature and available tools demonstrate the potential of AI in PM, further research is needed to tailor AI applications to specific organizational needs and to unlock their full potential. As AI technologies continue to evolve, their applications in Agile Project Management are likely to expand, further transforming how projects are managed in today's fast-paced and dynamic business environment.

3. Methodology

This study employs a qualitative research approach, combining thematic analysis (Castleberry, 2018) and case study methodology (Priya, 2021) to examine AI integration in project management. The case study approach was chosen for its ability to provide in-depth insights into the unique experiences and strategies of the participating organizations, while thematic analysis was selected to identify patterns and themes in the data. This combination enables a comprehensive understanding of the AI tools used and their impact on project management processes. The primary goal of the research is to identify and analyze the AI tools

utilized by four companies and explore how these tools are integrated into their project management practices. Qualitative data was gathered through semi-structured interviews with key stakeholders: Company A (Engineering Director), Company B (Lead Functional Architect), Company C (Engineering Manager), and Company D (CEO). Each case study reflects a distinct organizational perspective and approach to AI adoption.

The IT companies in this study chose to remain anonymous to protect their competitive position, intellectual property, and proprietary know-how—key assets in the tech industry. Strict confidentiality policies and concerns about misinterpretation of findings, which could harm reputation or trust, also influenced this decision (Lewicka, 2016; Lewicka, 2022; Lewicka et al., 2022). Legal or contractual obligations with partners further reinforced the need for discretion in this competitive and innovative sector.

Company A, a global technology provider with an "AI-first" strategy, applied tools like ChatGPT for project scoping, requirements analysis, and benchmarking. Microsoft 365 Copilot enhanced resource planning, communication, documentation, and multilingual support, while GitHub Copilot improved code delivery. AI also facilitated risk analysis, reporting, and executive summaries, enabling efficiency gains and strategic, human-centric activities despite privacy concerns.

Company B, a global provider of hospitality software solutions embedded in a non-IT-centric industry, adopted AI cautiously. ChatGPT was used selectively for API documentation and work breakdown structures, while other tools supported drafting, transcription, and document review. However, manual processes predominated due to trust issues, stringent data privacy requirements, and reliance on human judgment.

Company C, a digital media house, balanced exploratory AI applications with human oversight. Confluence's AI search provided quick information retrieval, Jira's AI supported ticket summarization, and GPT facilitated retrospective analysis. While these tools reduced manual effort, concerns about security and the limitations of AI judgment persisted.

Company D, a Polish micro-business and software house, leveraged Claude.AI to streamline tender participation. AI processed tender requirements, identified risks, and developed schedules, reducing analysis time significantly. Claude.AI built a knowledge base in a fixed-price project, generated requirement reports, and recommended team structures. The AI-prepared offer included a detailed budget, schedule, and risk plan, enhancing efficiency and competitiveness, particularly for smaller firms.

These cases highlight AI's transformative potential in project management, emphasizing diverse applications, challenges, and benefits tailored to organizational contexts. The study offers a broad yet nuanced perspective on AI adoption across varied project management environments by analyzing three globally operating companies and one micro-business.

4. Findings

The analysis of case studies from these organizations revealed some common patterns in how artificial intelligence (AI) tools are being adopted and implemented across different project management knowledge areas and process groups. Our research identified several improvements introduced by AI to project planning, execution, monitoring and control, and closure phases, along with different implementation approaches across the studied organizations.

Impact on Project Planning Processes. The research has shown significant benefits in project initiation and planning processes through adoption of AI tools. ChatGPT surfaced as a valuable tool for gathering information, requirements analysis and work breakdown structure (WBS) creation in the project scope management area. Company B's Lead Functional Architect noted, "Very helpful in WBS - work-breakdown structure, a deliverable-oriented breakdown of a project into smaller components with the help of the GPT." This adoption significantly reduced the time required for initial project scoping and planning while improving the robustness of project documentation. In project resource planning, AI tools were found useful or promising in team structure planning and resource allocation. Company D successfully used Claude.ai for matching team member skills with project requirements in public sector tenders. At the same time, Company A is testing and will soon benefit from enhanced resource and capacity planning with the help of Microsoft 365 Copilot.

These findings align with the research by Ruchit and Mitchell (Ruchit, Mitchell, 2024), which describes the potential of AI in enhancing project planning through improved forecasting, resource optimization, and risk assessment.

Enhancement of Project Execution. During the project execution phase, AI tools led to significant efficiency gains, especially within the communication management space. Microsoft 365 Copilot and ChatGPT were used for meeting documentation and stakeholder communications. The Engineering Director at Company A highlighted that "Communication preparation/review - preparation/redaction of emails during the whole project lifecycle, proofreading, translation, language adjustments" had become significantly more efficient.

The impact of AI on project execution resonates with the findings of multiple papers (Tursunbayeva, Chalutz-Ben Gal, 2024; Bahi et al., 2024; Karamthulla et al., 2024), which emphasize the role of AI in facilitating collaboration, knowledge sharing, and decision-making in project teams.

Monitoring and Control Processes. In analysed cases, AI tools also brought value to project monitoring and control processes. The Atlassian AI Suite improved task tracking and progress monitoring capabilities, particularly Jira AI. Company C's Engineering Manager reported that "Using Jira AI to summarize long tickets having a lot of text and comments or conversations to get the overview in no time" significantly helped monitor project progress and

identify potential issues early. In project risk management, AI tools help with risk identification and analysis. Company B utilized ChatGPT for "high-level risk analysis, brainstorming with GPT to understand risk & possible mitigation strategies." By utilizing Claude.AI, Company D identified and mitigated risks that could lead to exclusion. It presented a more thoughtful and polished consultant offer, increasing its competitiveness.

AI systems enhance the ability to monitor tender statuses and forecast outcomes, contributing to more efficient coordination in the tender evaluation process and enabling earlier decision-making regarding bid submissions, which resonates with Pesqueira (2024). These applications of AI in monitoring and control align with the research by Odejide and Edunjobi (Odejide, Edunjobi, 2024), which shows the potential of AI in project performance tracking, predictive analytics, and proactive risk management.

Project Closure and Knowledge Management. The case studies demonstrated significant efficiency gains in project closure and organizational learning processes through AI implementation. Confluence AI and ChatGPT were particularly valuable for knowledge management and documentation of lessons learned. Company C reported that "Confluence documentation holds tons of knowledge organized into separate docs" and highlighted how AI tools helped make this knowledge more accessible for future projects. In the same time the use of GPT helped analysed project retrospectives, "producing a document gathering all the categories, rates, and proposed action plans and providing insights and suggestions".

This finding resonates with the work of Gil et al. (Gil et al., 2021), who highlight the importance of effective knowledge management in project-based organisations and the potential of AI in facilitating knowledge capture, sharing, and reuse.

Tender Management Process. The micro-business (Company D) demonstrated innovative approaches to AI implementation in public sector project management, particularly in tender management processes. Their success in reducing tender analysis time from several hours to minutes showed how AI could enhance project planning and proposal development processes even in smaller organizations. AI significantly accelerates the stages of offer preparation and tender submission. Automating processes such as collecting and analyzing tender data enables companies to respond to opportunities more quickly and minimizes the risk of manual errors (Pesqueira, 2024).

Table 1 summarizes the AI tools the researched companies utilized during various project management phases. It highlights the specific tools implemented, their application areas, and the corresponding project stages, offering a concise overview of AI integration practices across the organizations studied.

Table 1.
Tools used in Project Management Phases in examined Companies (based on own research)

Project Management Phase	Company A (Global Technology Provider)	Company B (Global Hospitality Service Provider)	Company C (Scandinavian Media House)	Company D (Software House)
Scoping and planning	ChatGPT is used for gathering market insights, verifying existing use cases, and brainstorming ideas for project development, Microsoft 365 Copilot is being tested for resource and capacity planning	ChatGPT is employed to gather market insights, brainstorm ideas, and work breakdown structure; Gemini/Bard was also tested for a similar purpose, but it wasn't proved helpful at the point	ChatGPTused for gathering insights and brainstorming ideas, as a helpful assistant in the scoping phase	Claude.ai for matching team member skills with project requirements
Execution	Microsoft 365 Copilot is applied to meeting documentation and stakeholder communication processes; GitHub Copilot is used for "documentation from the code" and ensuring business and engineering alignment.	ChatGPT is used for meeting documentation and stakeholder communication processes, including creating various documents, presentations and training materials with graphics.	Jira AI and Confluence AI proved helpful for monitoring project progress and identifying potential issues early.	Claude.AI is used for the automated processing of tender documentation: analysis of the mandatory conditions, including qualification criteria, to ensure that the company meets all formal requirements.
Monitoring and Control	ChatGPT is used for high-level risk assessment and mitigation strategies, enhanced reporting, and forecasting while operating on big datasets	ChatGPT helped with high-level risk assessment and mitigation strategies	Jira AI and Confluence AI are employed for monitoring project progress and identifying potential issues early	Claude.AI is used for identifying key risks associated with the tender, including contractual penalties for delays in providing specialists, tight deadlines requiring intensive planning and the obligation to provide bid security, impacting the firm's financial liquidity analysis
Closure and Knowledge Management	Microsoft 365 Copilot is used for improved documentation management	ChatGPT is treated "as StackOverflow or Google" for enhanced research and knowledge base	Atlassian AI (Jira AI, Confluence AI) for improved documentation and ChatGPT for analysis, summary, and conclusions/key takeaways from project retrospectives	Final offer generation with Claude.ai, including - a detailed schedule - budget divided into stages - proposed team

Source: own work.

The experimentation, use, and integration of AI tools have also led to an evolution in the project manager role. Project managers have shifted focus toward more strategic management aspects, with AI handling routine and research-intense tasks across various areas. As observed by all interviewees, there has been "increased focus on strategy, AI oversight, or upskilling in data and AI tools," indicating a transformation in how project managers perceive and approach their changing core responsibilities.

This evolution aligns with the trend described by Odejide and Edunjobi (Odejide, Edunjobi, 2024), with AI expanding human capabilities by providing support, insights, and recommendations. The role of the project manager is evolving towards a more technical and analytical approach while maintaining a key focus on human resource management and stakeholder communication. (Mohammad, Chirchir, 2024) The changing role of project managers in the case studies illustrates that they leverage AI tools to improve the efficiency of different project management aspects while maintaining strategic oversight.

Despite the benefits, organizations face several challenges in implementing AI within project management processes. Privacy and security concerns were often considered significant, particularly in companies handling sensitive project data or lacking enterprise data protection agreements with tool providers. Company B emphasized the challenge of balancing AI tool adoption with data protection requirements in project documentation and communication processes, while for Company C, not having enterprise “sand-boxed” solutions was a clear obstacle for broader AI adoption. An important aspect is managing the ethical and social risks associated with AI, such as data privacy and the transparency of algorithmic decisions. Project managers must actively participate in developing governance frameworks that ensure appropriate ethical standards and compliance with regulations (Pesqueira 2024). Technical limitations such as model “hallucinations” or AI tool shortcomings also presented challenges across various project management areas. The need for human validation of AI-generated content was often raised, with Company C's Engineering Manager noting that "Every response has to be carefully evaluated for false information" and Company B’s Lead Functional Architect stating that “The answer you get from ChatGPT can be as good as bad”. In project management practice, AI hallucinations can impact the effectiveness of project planning by leading to incorrect conclusions about resources, costs, or schedules. This highlights the need to integrate human expertise with AI-generated outputs (Mohammad, Chirchir, 2024).

These findings demonstrate the importance of proper AI governance and human oversight, as emphasized by multiple authors, including Rakova et al. (2020) and Odejide and Edunjobi (2024).

5. Conclusion

Integrating Artificial Intelligence (AI) into project management processes represents a transformative shift, as evidenced by our research findings and supported by a comprehensive review of existing literature. Our case studies demonstrate that AI adoption enhances various project management phases, from planning and execution to monitoring, control, and closure. These findings align with broader trends in the literature, solidifying the understanding of AI's growing role in modern project management practices.

Our research revealed significant improvements in project planning processes, particularly in scope and resource management. Tools like ChatGPT and Microsoft 365 Copilot have been pivotal in reducing the time needed for tasks like work breakdown structure creation and resource allocation while enhancing documentation accuracy. These observations echo findings in the literature (Ruchit, Mitchell, 2024), highlighting AI's potential in forecasting, resource optimization, and proactive risk assessment. During project execution, AI has driven efficiency gains in communication and task coordination. Tools like Microsoft 365 Copilot and Atlassian AI Suite were instrumental in streamlining stakeholder interactions and documentation, as corroborated by studies that emphasize the role of AI in promoting collaboration and decision-making (Tursunbayeva, Chalutz-Ben Gal, 2024).

Furthermore, our findings underline the value AI brings to monitoring and control processes, such as risk identification, progress tracking, and tender evaluation, mirroring the insights of Odejide and Edunjobi (2024) on AI's predictive and proactive capabilities. Knowledge management and project closure processes have also been notably enhanced through AI adoption. AI tools like ChatGPT and Confluence AI facilitated capturing, organizing, and disseminating project learnings, supporting continuous improvement in future initiatives. These findings align with the work of Gil et al. (2021), which underscores the importance of AI in fostering knowledge sharing and reuse in project-based organizations.

The literature also provided a vital context for understanding the evolution of the project manager's role in light of AI integration. Our research confirmed a shift toward more strategic responsibilities, with project managers increasingly focusing on AI oversight, stakeholder engagement, and upskilling in data and AI tools. This transition resonates with observations by Odejide and Edunjobi (2024) and others, who describe the growing importance of technical and analytical skills in project management. However, both our findings and the literature highlight critical challenges in AI adoption, including privacy concerns, ethical risks, and technical limitations like AI hallucinations. Organizations need robust governance frameworks and human oversight to mitigate these issues effectively. Additionally, the literature and our research underscore the necessity of balancing AI insights with human expertise to ensure accurate and contextually relevant outcomes.

The integration of AI into project management, as observed in our research and supported by the literature, offers significant benefits while presenting challenges requiring thoughtful navigation. As AI tools evolve, their potential to enhance project planning, execution, monitoring, and knowledge management will only increase. Organizations can harness AI's capabilities to drive efficiency, adaptability, and success by addressing ethical considerations and technical limitations. Our findings contribute to this growing body of knowledge, offering practical insights into the transformative impact of AI on project management

6. Limitations and Future Research

The study identified clear trends in how AI is reshaping project management practices. All organizations anticipated increased AI integration across the board, including project management processes, though with different approaches to implementation. Company B's Lead Functional Architect noted, "AI adoption in our work routine will still come". However, this was consistently balanced with an emphasis on maintaining human-centered project management approaches, with AI serving as a support tool or an extension rather than a replacement for project manager judgment across all knowledge areas.

Future research should focus on several critical areas to address the limitations of integrating AI into agile Project Management. Firstly, exploring advanced AI techniques, such as deep learning and reinforcement learning, is essential for tackling more complex Project Management tasks. These technologies could offer stronger predictions and optimizations for intricate project scenarios, improving decision-making and project outcomes. Additionally, investigating the interplay between AI and agile methodologies across various industries and project types will provide insights into how AI can be applied more effectively in different contexts, maximizing its potential benefits.

Another critical focus should be on improving the quality and availability of data used to train AI models. Research into data cleansing methods, integrating diverse data sources, and creating frameworks for data governance will ensure that AI tools are based on high-quality, accurate data. Moreover, ethical considerations around AI implementation in Project Management must be addressed. This includes tackling AI bias, ensuring transparency, and establishing clear guidelines for the ethical use of AI in project environments.

Additionally, examining the dynamics of human-AI collaboration in project teams will be key to enhancing the overall effectiveness of AI integration. Understanding how AI can complement human decision-making and help project managers make better-informed choices is vital for maximizing utility. Future studies should also explore the development and testing of new agile frameworks that incorporate AI as a core component. These frameworks would

allow AI to function effectively within agile environments while preserving the flexibility and adaptability that agile methodologies prioritize.

The cases analyzed in our study involved three international companies operating in the Polish IT sector and one small Polish IT enterprise. These case studies provided valuable insights into the application of AI in agile Project Management across different organizational contexts. However, future research would need to be conducted on a larger scale and across different sectors to validate and expand upon these findings. This broader scope will help better understand the full potential of AI in agile Project Management and its adaptability to various industries and organizational sizes.

Future studies will contribute to a deeper understanding of how AI can be optimally integrated into agile Project Management by focusing on these research areas. This will drive further improvements in project outcomes, efficiency, and innovation. As AI continues to evolve, its thoughtful and adaptive implementation will allow project managers to leverage its full potential, enabling more significant success in an increasingly complex and dynamic business landscape.

References

1. Adegbite, A.O., Adefemi, A., Ukpoju, E.A., Abatan, A., Adekoya, O., Obaedo, B.O. (2023). Innovations in project management: trends and best practices. *Engineering Science & Technology Journal, 4(6)*, pp. 509-532.
2. Bainey, K. (2024). *AI-Driven Project Management: Harnessing the Power of Artificial Intelligence and ChatGPT to Achieve Peak Productivity and Success*. John Wiley & Sons.
3. Bi, M., Kovalenko, I., Tilbury, D.M., Barton, K. (2024). Dynamic distributed decision-making for resilient resource reallocation in disrupted manufacturing systems. *International Journal of Production Research, 62(5)*, pp. 1737-1757.
4. Castleberry, A., Nolen, A. (2018). Thematic analysis of qualitative research data: Is it as easy as it sounds? *Currents in pharmacy teaching and learning, 10(6)*, pp. 807-815.
5. Ciric Lalic, D., Lalic, B., Delić, M., Gracanin, D., Stefanovic, D. (2022). How project management approach impact project success? From traditional to agile. *International Journal of Managing Projects in Business, 15(3)*, pp. 494-521.
6. Gil, J., Martinez Torres, J., González-Crespo, R. (2021). The application of Artificial Intelligence in Project Management research: A review. *International Journal of Interactive Multimedia and Artificial Intelligence, 6(6)*.
7. Karamthulla, M.J., Prakash, S., Tadimarri, A., Tomar, M. (2024). Efficiency unleashed: Harnessing AI for agile Project Management. *International Journal For Multidisciplinary Research, 6(2)*, pp. 1-13.

8. Kasaraneni, R.K. (2021). AI-Enhanced Supply Chain Collaboration Platforms for Retail: Improving Coordination and Reducing Costs. *Journal of Bioinformatics and Artificial Intelligence, 1(1)*, pp. 410-450.
9. Lewicka, D. (2022). Building and rebuilding trust in higher education institutions (HEIs). Student's perspective. *Journal of Organizational Change Management, 35(6)*, pp. 887-915.
10. Lewicka, D., Starowicz-Rajca, H., Blbas, R., Wilczewski, A. (2024). Cultivating success: A practical exploration of applying artificial intelligence in human resources management. *Scientific Papers of Silesian University of Technology. Organization & Management [Zeszyty Naukowe Politechniki Slaskiej. Seria Organizacji i Zarzadzanie], 199*.
11. Lewicka, D., Zakrzewska-Bielawska, A. (2016). Rola zaufania w relacyjnej orientacji przedsiębiorstwa. In: G. Osbert-Pociecha, S. Nowosielski (Eds.), *Meandry teorii i praktyki zarządzania*. Wrocław: Wydawnictwo UE we Wrocławiu.
12. Lewicka, D., Zakrzewska-Bielawska, A.F. (2022). Trust and distrust in interorganisational relations — Scale development. *PloS one, 17(12), e0279231*.
13. Manchana, R. (2022). Optimizing Real Estate Project Management through Machine Learning, Deep Learning, and AI. *Journal of Scientific and Engineering Research, 9(4)*, pp. 192-208.
14. Mohammad, A., Chirchir, B. (2024). *Challenges of Integrating Artificial Intelligence in Software Project Planning: A Systematic Literature Review*.
15. Muda, I., Almahairah, M.S., Jaiswal, R., Kanike, U.K., Arshad, M.W., Bhattacharya, S. (2023). Role of AI in Decision Making and Its Socio-Psycho Impact on Jobs, Project Management and Business of Employees. *Journal for ReAttach Therapy and Developmental Diversities, 6(5s)*, pp. 517-523.
16. Nayebi, M., Kabeer, S.J., Ruhe, G., Carlson, C., Chew, F. (2018). Hybrid Labels are the New Measure! *IEEE Software, 35*, pp. 54-57.
17. Odejide, O.A., Edunjobi, T.E. (2024). AI in Project Management: exploring theoretical models for decision-making and risk management. *Engineering Science & Technology Journal, 5(3)*, pp. 1072-1085.
18. Parekh, R., Mitchell, O. (2024). Utilization of artificial intelligence in project management. *International Journal of Science and Research Archive, 13(1)*, pp. 1093-1102. Retrieved from: https://doi.org/10.30574/ijsra.2024.13.1.1779.
19. Pesqueira A., de Bem Machado A., Bolog S., Sousa M.J., Pereira R. (2024). Exploring the impact of EU tendering operations on future AI governance and standards in pharmaceuticals. *Computers & Industrial Engineering, Vol. 198, 110655.*
20. Priya, A. (2021). Case study methodology of qualitative research: Key attributes and navigating the conundrums in its application. *Sociological Bulletin, 70(1)*, pp. 94-110.
21. Rakova, B., Yang, J., Cramer, H., Chowdhury, R. (2021). Where responsible AI meets reality: Practitioner perspectives on enablers for shifting organizational practices. *Proceedings of the ACM on Human-Computer Interaction, 5(CSCW1)*, pp. 1-23.

22. Rankovic, N., Rankovic, D., Ivanovic, M., Lazic, L. (2021). A new approach to software effort estimation using different artificial neural network architectures and Taguchi orthogonal arrays. *IEEE Access, 9*, 26926-26936.
23. Russell, S., Norvig, P. (2021). *Artificial intelligence: a modern approach*. AIMA. Retrieved from: https://aima.cs.berkeley.edu/, 26.02.2023.
24. Tan, Y.Q., Shen, Y.X., Yu, X.Y., Lu, X. (2023). Day-ahead electricity price forecasting employing a novel hybrid frame of deep learning methods: A case study in NSW, Australia. *Electric Power Systems Research, 220, 109300*.
25. Tursunbayeva, A., Chalutz-Ben, Gal, H. (2024). Adoption of artificial intelligence: A TOP framework-based checklist for digital leaders. *Business Horizons, 67(4)*, pp. 357-368. Retrieved from: https://doi.org/10.1016/j.bushor.2024.04.006.
26. Victor, N.O.C. (2023). *How Artificial Intelligence Influences Project Management*.
27. Weng, W.H., Sellergen, A., Kiraly, A.P., D'Amour, A., Park, J., Pilgrim, R., Pfohl, S., Lau, C., Natarajan, V., Azizi, S., Karthikesalingam, A. (2024). An intentional approach to managing bias in general purpose embedding models. *The Lancet Digital Health, 6(2), e126-e130*.
28. Zadeh, E.K., Khoulenjani, A.B., Safaei, M. (2024). Integrating AI for Agile Project Management: Innovations, challenges, and benefits. *International Journal of Industrial Engineering and Construction Management (IJIECM), 1(1)*, pp. 1-10.
29. Zhou, W., Yan, Z., Zhang, L. (2024). A comparative study of 11 non-linear regression models highlighting autoencoder, DBN, and SVR, enhanced by SHAP importance analysis in soybean branching prediction. *Scientific Reports, 14(1), 5905*.

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APPLICATION OF CHROMATOGRAPHIC DATA SEPARATION METHODS IN QUALITATIVE AND QUANTITATIVE DATA ANALYSIS

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Purpose: Currently, one of the significant limitations of problems related to data mining using classical classification methods, the results of which are used in the decision-making process, is the processing of large data sets. The first significant limitation in the use of classical classification methods is the need to ensure a constant data size. The second type of limitation is related to the dimension of the data. The last type of limitation that occurs when using classic classification algorithms is associated with the situation that a given input vector may contain data belonging to many classes simultaneously, then we are talking about the so-called multiclass vectors. On the other hand, as a result of processing large data sets, we want to obtain information that is not only qualitative but equally important in the decision-making process is quantitative information.
Design/methodology/approach: This work presents data classification methods based on the gas chromatography technique, which in issues related to the classification of large data sets are not subject to the above limitations and provide quantitative and qualitative information.
Findings: The article presents classification results for selected data sets. In the first case, the process of classifying sets was carried out, the individual vectors contained several tens of thousands of elements and several thousand attributes. Direct classification of vectors of such dimensions using commonly known methods without reducing the dimension of the data is practically impossible. The second type of data set is a heterogeneous set, i.e. a set containing various types of data, where, as in the first case, the input data vectors are suitably long. The third type of test data set is a multi-class set, during the classification of this set qualitative information is provided, as is the case with classic data mining methods, and quantitative information, which is a unique feature of unproposed data classification methods.
Originality/value: The article proposes an innovative method for the classification of multidimensional data based on the method of chromatographic separation of substances in gas chromatography. This method can be used in the classification of multi-class variable-length data vectors. This work shows that based on the chromatographic separation method, we obtain information also of a quantitative nature, and not only of a qualitative nature.
Keywords: natural computing algorithms, chromatographic separation, signal processing; data mining.
Category of the paper: Research paper.

1. Introduction

Nowadays, one of the important issues of machine learning is the processing of large data sets. Issues related to large data sets refer primarily to data sets that contain a large volume of data and data sets that are complex, i.e. they do not have a specific structure as in the case of data sets represented using a relational database, and also the spectrum of data types stored in this type of collections is wide ranging from text in natural language and a stream of numerical data through a set of graphic images to audio and video data (Hilbert, 2016; Reinsel et al., 2017).

The article presents an algorithm that can be used in issues related to the classification of large-scale data sets. The motivation to define this type of algorithm was the fact that currently the methods used to process this type of data are subject to several significant limitations.

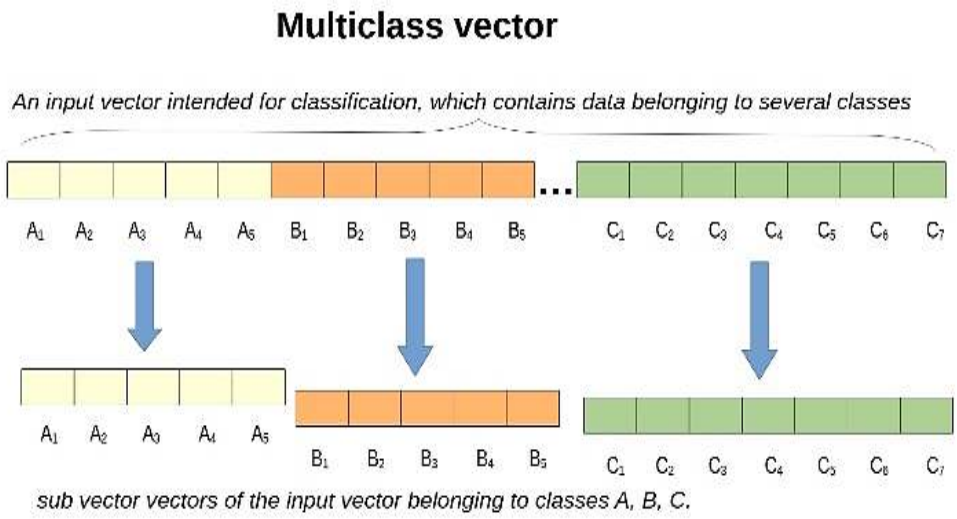

Figure 1. Multiclass vector structure.

The first significant limitation in the use of classical classification methods is the need to ensure a constant size of data - vectors that will be subject to the classification process. The second type of limitation is related to the dimension of the data. When we use classical methods for classifying large vectors, we always have to reduce the dimension of the input vectors using selected mathematical statistics methods (Hilbert, 2016; Reinsel et al., 2017).

Another limitation of currently used algorithms is that the classified data must be homogeneous, i.e. there can only be one type of data. If images are classified, non-image data whose data source is another phenomenon and which is in some way related to the classified images cannot also be classified as input. Finally, the last type of limitation that occurs when using classic classification algorithms is related to the situation that a given input vector may contain data belonging to many classes at the same time, and then in this article we are talking about the so-called called multi-class vectors (Brabazon et al., n.d.).

Moreover, it would be advisable that when processing the above type of data sets, the algorithms should provide both qualitative information, as is the case in most of the algorithms used, but also quantitative information.

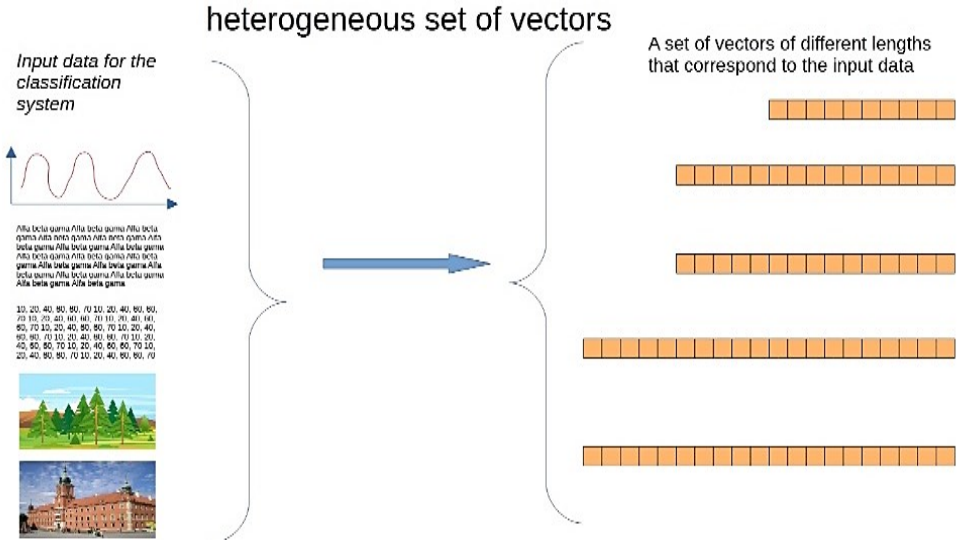

Figure 2. Vector structure of a heterogeneous set of vectors.

The presented algorithm attempts to solve the problems defined above. The presented algorithm attempts to solve the problems defined above. The algorithm is inspired by the method of chromatographic separation of substances, which is used in analytical chemistry. The first chapter of the article will present the principle of chromatographic data separation, which is the basis of the defined algorithm. The second chapter will present an algorithm for data classification, which is inspired by the principles of chromatographic separation of substances using gas chromatography. The following parts of the article will present the results of calculations and classification for example data sets.

2. Properties of chromatographic separation of substances

Chromatography – an analytical technique used to separate or examine the composition of mixtures of chemical compounds. In each chromatographic technique, the mixture being tested is first separated and then the individual components are detected (Leweke, von Lieres, 2018; Pierce et al., 2021; Stilo et al., 2021). The substance is separated by passing the solution of the tested mixture through a specially prepared separation phase (bed), also called the stationary phase. The separation phase consists of substances that have sorption abilities or can otherwise affect the flowing substances. The intensity of this process varies for individual components of the mixture. Some components therefore remain in the phase longer and others for a shorter time, which allows them to be separated. The time a given component stays in the column is called the retention time (Blumberg, 2021; Pierce et al., 2021). Generally speaking,

chromatographic separation is a process in which a mixture of chemical compounds is separated into at least two fractions with different compositions. From a chemical point of view, the purpose of the substance separation process is to increase the concentration of one of the components of the initial mixture about the remaining components of the initial mixture. Separation takes place using physical methods and chemical reactions.

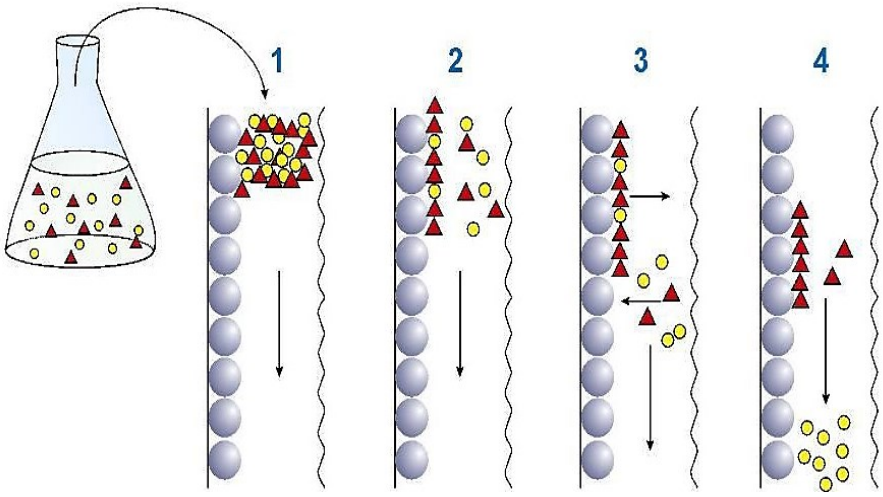

Figure 3. The idea of chromatographic separation of substances.

Source: https://chemia.ug.edu.pl/sites/default/files/_nodes/strona-chemia/17427/files/wyklad5_new.pdf

Figure 3 presents the chromatograph process, the idea of separating a mixture using chromatography we can see, the mixed substance is introduced at the entrance of the chromatographic column. The chromatographic column is filled with a substance or substances that have a different degree of affinity for the substances that are being separated - they have been introduced into the chromatographic column (Varhadi et al., 2020). Due to the above, the time it takes for each substance to leave the chromatographic column will be different and will depend on the degree of affinity of a given substance for substances that are in the stationary phase. The output data stream of the chromatograph is the relationship between the concentration of a given substance over time. This relationship is presented by a chromatograph, i.e. a graph showing the relationship between the concentration of a given substance and the time needed to leave the chromatographic column, i.e. the retention time (Giddings, 2017; Robards, Ryan, 2021).

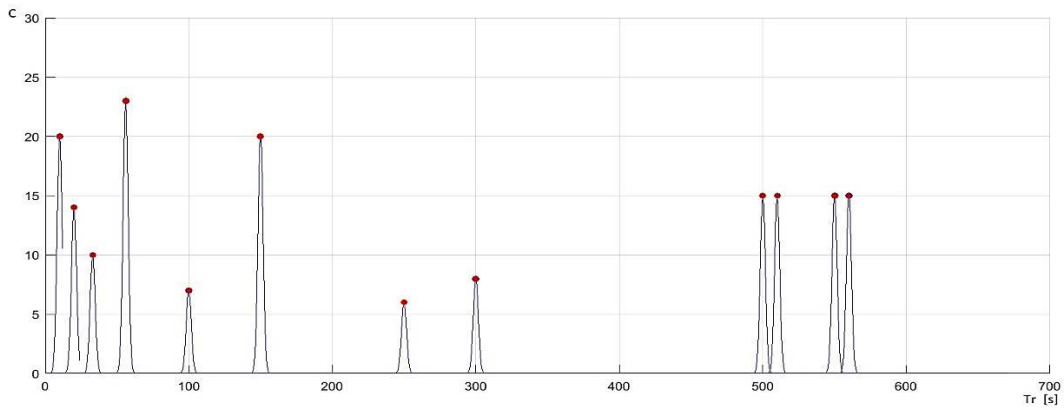

Figure 4. Graph of the substance concentration in the eluate flowing from the column as a function of the elution volume, and when the eluent flow rate is constant as a function of time.

As is known, the retention time of a given substance is characteristic and depends on the structure of the stationary phase and the structure of the substance being separated.

The chromatographic column is filled with a substance or substances that have a different degree of affinity for the substances that are being separated - they have been introduced into the chromatographic column (Hage, 1999; Urh et al., 2009; Varhadi et al., 2020). Due to the above, the time it takes for each substance to leave the chromatographic column will be different and will depend on the degree of affinity of a given substance for substances that are in the stationary phase. The output data stream of the chromatograph is the relationship between the concentration of a given substance over time. This relationship is presented by a chromatograph, i.e. a graph showing the relationship between the concentration of a given substance and the time needed to leave the chromatographic column, i.e. the retention time. As is known, the retention time of a given substance is characteristic and depends on the structure of the stationary phase and the structure of the substance being separated.

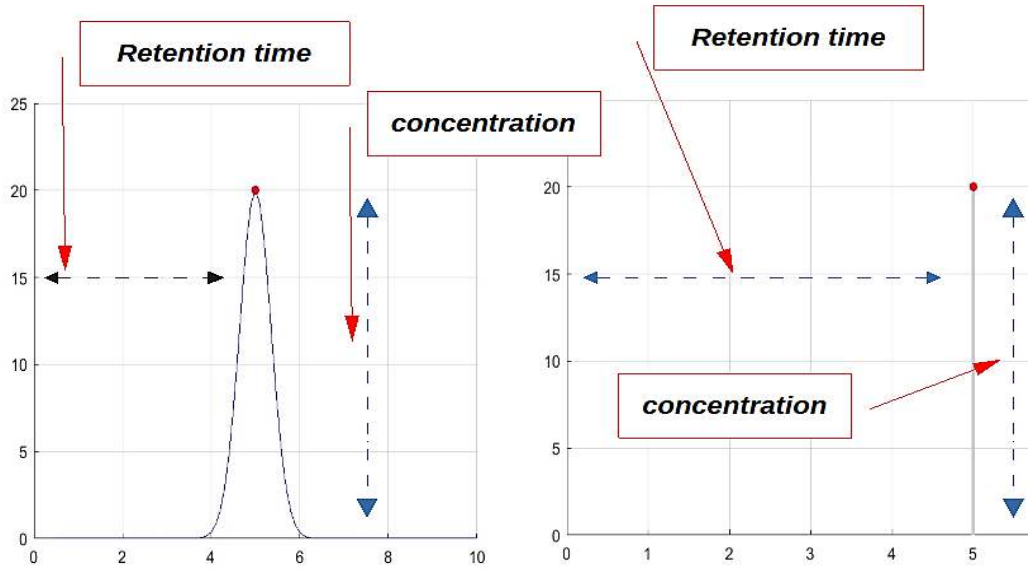

Figure 5. Substance identification: peak position, Peak height: quantification.

Figure 5 shows a signal output generated by the chromatograph. This signal provides two important pieces of information: firstly, it provides information about the type of substance, which is responsible for the retention time - individual for each substance. The second type of information is quantitative information, how much of a specific substance was in the tested mixture. This is determined by the height of the peak, which informs about the concentration of the tested substance at the output of the chromatographic column (Hohrenk et al., 2020; Pezzatti et al., 2020; Witting, Böcker, 2020).

The figure on the left shows the output from a real chromatography system. The figure on the right shows the output signal generated by the presented algorithm. You can see that in this case we are dealing with an ideal peak, the output signal is not blurred due to, for example, detector imperfections.

3. Definition of chromatographic data separation algorithm

The chromatographic data separation algorithm is based on the basic paradigm that the processed data string is a complex chemical molecule with a chain-linear structure. This means that each data vector or set of vectors will be processed by the chromatographic algorithm in accordance with the rules that apply in the real chromatographic system (Święcicki, 2024).

The general principle of operation of the chromatographic data separation algorithm will be to treat the data vector as a mixture of chemical compounds and for each "chemical" compound the relationship between the concentration of a given substance at the output of the chromatographic system is calculated. In other words, it will involve calculating the spectrum as shown in the figure. In the first phase, we treat the vector of numbers as a polyatomic molecule with a linear structure. In the next phase, the molecule is divided into smaller molecules. In the last phase of the algorithm, each newly created molecule is processed by the chromatographic column, i.e. the retention time is calculated. As a result of these operations, a chromatogram is created, i.e. a graph describing the concentration of a given type of molecules as a function of time at the output of the "chromatographic" column. This relationship, i.e. the chromatogram, is later called the spectrum of a given starting substance.

The chromatographic data separation algorithm consists of the following sequence of operations, which are inspired by the functioning of a real chromatographic system:

1) Mixture creation phase for a given vector.
2) Retention time calculation phase.
3) Chromatogram creation phase.
4) Phase of the analysis chromatogram.

3.1. The phase of creating a mixture for a given

In the first phase of this algorithm, a set of vectors W consisting of any number of vectors of any length is transformed into a set of mixtures of substances through the process of dividing the fragmentation into smaller vectors of the same length. The fragmentation of the vector takes place in such a way that for each element from the set *W*, a mixture of substances is created that corresponds to this element of the set *W*.

Input data
$W=\{w_1,w_2,w_3....w_N\}$ – a set of data vectors that will be processed
Output data
set of substances $\mathbf{MS_i}$,that have been processed by a chromatographic column, i.e. they have a calculated retention time t_r
$\mathbf{MS_{i..M}=[];}$
$\mathbf{W=\{w_1, w_2, ...w_M\}}$
Foreach w ϵ W

1 For a given w_i data vector, create a mixture of substances - it will fragment the vector into sub-vectors of constant length
$\mathbf{MS_i=\{s_1, s_2, ...s_{M(i)}\}}$
$\mathbf{MS_i}$ *-a set of substances is created by dividing a vector into sub-vectors according to the adopted principle of division,*
$\mathbf{ms_i}$ *- the elements of this set is the set of substances resulting from the division of the vector* $\mathbf{w_i}$*,this means that the set will contain individual substances s which are not subject to further subdivision*
$\mathbf{ms_{M(i)}:=\{s_1, s_2, ...s_{M(i)}\}}$ *a substance that was created by splitting the wi vector.* $\mathbf{w_i}$.
2 ***Foreach s ϵ*** $\mathbf{ms_i}$
3 ***Calculate Retention Time*** *// t_r – the residence time of the substance in the stationary phase e.g.*
// according to the formula (5)
4 ***End***
End

Algorithm 1. Algorithm transforming a set of vectors into a set of chromatograms.

As shown in the algorithm presented above, the set of mixtures of substances that has been created is fed to the input of a "virtual chromatographic column" in which the process of migration of a given substance between the stationary phase and the mobile phase takes place.

3.2. Phase of calculating the retention time

The value of the retention time t_r depends on the affinity of the stationary phase for a given substance, which is an important value in the classification process. It is known that the value of the retention time depends on the affinity of the substance for the stationary phase that is filled in the chromatographic column. The final fragment of Algorithm 1**.** contains a sequence calculating the retention time value.

3.3. Chromatogram creation phase

The next stage of the presented algorithm is to create a chromatogram for a given mixture of substances that corresponds to the w_i element. The chromatogram is created as a result of the

registration of individual substances at the output of the chromatographic column. The moment at which a given substance will leave the chromatographic column depends on the retention time t_r. The purpose of the detector is to count the molecules of substances leaving the chromatographic column at a given moment of time.

Input data
For a given set of substances ***MS$_i$*** *,that have been processed by a chromatographic column, i.e. they have a calculated retention time* t_r
Output data
CH =$\{ch_1, ch_2, ch_3 \ldots ch_N\}$ *– a set of chromatograms, where each element of this set represents a chromatographic spectrum corresponding to a given element of the set W*
$ch_i = \{peak_1, peak_2, peak_3 \ldots peak_M\}$ *– Each chromatogram consists of a set of peaks*
ch_i***=[];***
Foreach s ϵ MS$_i$
peak$_i$[s.Tr]:=peak$_i$[s.Tr]+1 *// Calculation of "concentration" under a vector with a given retention time*
end

Algorithm 2. Algorithm for creating a ch_i chromatogram for a mixture belonging to the w_i vector.

To sum up, the operation of the two algorithms presented above, which model the processes occurring in a real chromatograph, can be presented below in a formalized notation that will later be used in the analysis of the algorithm. Let us assume that the stationary phase *FS* is an *m*-element vector as shown in equation (1) while the substance vector that was created as a result of the algorithm in the fragmentation process as a result of the operation of the first algorithm 1 is also an array with dimensions *NxM* presented in equation (2)

$$FS = \left(fs_1, fs_2, fs_3 \ldots fs_M\right) \tag{1}$$

$$S = \begin{bmatrix} s_{1,1}, s_{1,2}, s_{1,3} \ldots\ldots s_{1,M} \\ s_{2,1}, s_{2,2}, s_{3,1} \ldots\ldots s_{3,M} \\ \ldots\ldots\ldots \\ s_{N,1}, s_{N,2}, s_{N,1} \ldots\ldots s_{N,M} \end{bmatrix} \tag{2}$$

As we know, a chromatogram is made up of peaks, and a single peak is a pair of numbers, the first of which is the retention time t_r and the second is the concentration of substance C, formula (3), as the result of the operation of .

$$peak_i = \left(tr_i, C\right) \tag{3}$$

The retention time can be calculated using the F_{tr} function, which calculates the retention time value for a given substance and the vector describing the stationary phase (4).

$$tr_i = F_{tr}\left(S_{i,1\ldots M}, FS\right) \tag{4}$$

When calculating the retention time, the function calculates the retention time for a given substance taking into account the structure, i.e. the values of the stationary phase. For the purposes of further considerations, it can be assumed that the function calculating the retention time is expressed by formula (5).

$$tr_i = F_{tr}\left(S_{i,1\ldots M}, FS\right) = \sum_{k=1}^{M}\left(s_{i,k} \cdot fs_k\right) \tag{5}$$

As the presented formula shows, the scalar product of two vectors is calculated. The more similar the vectors are to each other, the greater the value of the calculated product, the greater the retention time for a given substance.

3.4. Chromatogram formation phase

The next stage of the presented algorithm is to create a chromatogram for a given mixture of substances that corresponds to the w_i element. The chromatogram is created as a result of the registration of individual substances at the output of the chromatographic column. The moment at which a given substance will leave the chromatographic column depends on the retention time t_r. The purpose of the detector is to count the molecules of substances leaving the chromatographic column at a given moment of time.

3.5. Spectrum analysis phase

The last stage of recognizing substances that have been processed by the chromatographic system is the stage of classifying the output chromatographic spectrum and assigning it to the spectra of known substances.

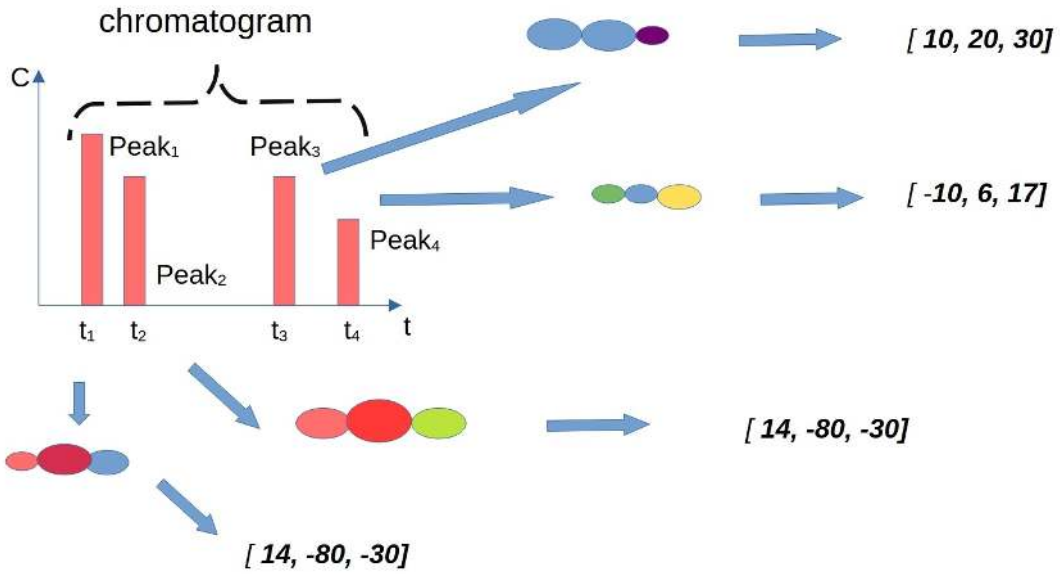

Figure 6. Structure of the chromatogram - the spectrum corresponding to the w_i vector.

The chromatogram of the tested mixture of substances describes the concentration of individual compounds of the fractions included in the tested substance or mixture, which were separated as a result of the chromatographic process, similarly to the presented algorithm. As shown in the figure above, as a result of the chromatography process, we obtain a chromatogram containing many peaks corresponding to the concentration of the "substance" that resulted from the operation of algorithm 1. The task of the classification algorithm will be

to assign the ch_x chromatogram to the chromatograms of known vectors, using the matching criterion, which is the peak retention time.

The last element of the data classification method discussed in this work is chromatogram classification. The previous points presented the structure of the chromatogram, which consists of peaks, and each peak has two attributes, namely its position on the level axis and the concentration of a given molecule, which is determined by the height of the peak.

This means that each chromatogram of the tested substance consists of a set of peaks, not necessarily in the same number. Having a set of chromatograms of reference substances, we can assign the chromatogram of the tested substance to the set of chromatograms of reference substances.

In this work, the assignment of the chromatogram of the tested substance to the set of reference chromatograms will be done on a different basis than as shown in work (Święcicki, 2024). Therefore, the time complexity of the previously proposed algorithm (Święcicki, 2024) was a significant problem in the case of a large number of chromatograms.

For this purpose, the following assumption was made that a given chromatogram is a set of points in n-dimensional space. The size of this space is determined by the design of the detector in the case of a physical chromatograph - that is, the detector is responsible for the sensitivity of the system, and this is also the case with the presented algorithm. A more sensitive detector will be able to identify the time moments in which particular fractions of the tested substances (i.e. vectors) appear at the output of the chromatographic column with greater accuracy. Individual moments of time refer to the retention time. It is known that in the case of the presented algorithm, the identification of retention time is important and determines the quality of the classification process.

For the needs of the presented algorithm, the time moments in which the detector will identify the concentration of a given fraction have been quantized, i.e. the retention time has been assumed to take a value that will correspond to the detector's operation, i.e. it is assumed that the detector in the presented algorithm is a discrete element when it comes to identifying the time moments in which the identified are the concentrations of individual fractions.

For such assumptions, the algorithm for assigning the chromatogram of an unknown "substance", i.e. a subvector that was created as a result of the fragmentation process, will take a simpler form compared to the algorithm presented in work (Święcicki, 2024)

Let us assume that the set of chromatograms is represented by a matrix of dimensions M by N. In this case, M will represent the number of reference chromatograms, while N will correspond to the maximum number of peaks in the chromatogram. N will depend on two factors, firstly, the accuracy of the detector - and in the case of the presented algorithm, the distance between time points, secondly, what retention time interval will be considered, and this depends on the classified data and the structure of the stationary phase. Formulas (6) and (7) show the proposed notation. If the chromatogram for a given column does not have a peak, the value zero is entered because the table columns clearly determine the retention time.

$$SetOfChrom=\begin{bmatrix} peak_{1,1}, peak_{1,2}, peak_{1,3}..... peak_{1,N} \\ peak_{2,1}, peak_{2,2}, peak_{3,1}..... peak_{3,N} \\ ..... \\ peak_{M,1}, peak_{M,2}, peak_{M,1}..... peak_{M,N} \end{bmatrix} \tag{6}$$

$$Ch_x=\left[peak_1, peak_2, peak_3..... peak_N \right] \tag{7}$$

On the other hand, it is known that each peak consists of two attributes (3): retention time and concentration of a given substance. Two matrices will then be used to represent the set of chromatograms. A matrix containing information about retention times, marked with the symbol *Tr*, and a matrix *C* containing information about the height of a given peak, i.e. the concentration of a given fraction. What is represented by the formulas (8) and (9).

$$SetOfTr=\begin{bmatrix} tr_{1,1}, tr_{1,2}, tr_{1,3}.....tr_{1,N} \\ tr_{2,1}, tr_{2,2}, tr_{3,1}.....tr_{3,N} \\ ..... \\ tr_{M,1}, tr_{M,2}, tr_{M,1}.....tr_{M,N} \end{bmatrix} \tag{8}$$

$$SetOfC=\begin{bmatrix} c_{1,1}, c_{1,2}, c_{1,3}..... c_{1,N} \\ c_{2,1}, c_{2,2}, c_{3,1}..... c_{3,N} \\ ..... \\ c_{M,1}, c_{M,2}, c_{M,1}..... c_{M,N} \end{bmatrix} \tag{9}$$

$$Tr_x=\left[tr_1, tr_2, tr_3.....tr_N \right] \tag{10}$$

$$C_x=\left[c_1, c_2, c_3..... c_N \right] \tag{11}$$

The T matrix will be able to provide qualitative information, while the C matrix will be used for calculations that will provide quantitative information.

With this notation, performing calculations aimed at identifying an unknown chromatogram will involve performing relatively simple mathematical operations. Let us assume that the distance between two chromatograms will be measured using the cosine metric.

$$max\left(SetOfTr \cdot Tr_x^T \right)=max\left(\begin{bmatrix} tr_{1,1}, tr_{1,2}, tr_{1,3}.....tr_{1,N} \\ tr_{2,1}, tr_{2,2}, tr_{3,1}.....tr_{3,N} \\ ..... \\ tr_{M,1}, tr_{M,2}, tr_{M,1}.....tr_{M,N} \end{bmatrix} \cdot \left[trx_1, trx_2, trx_3.....trx_N \right]^T \right) \tag{12}$$

With this metric defined, finding the best match for an unknown chromatogram will come down to calculating formula (10) and finding the element with the highest value. The coordinates of this element will uniquely identify the chromatogram that best matches the identified chromatogram and thus the class to which this chromatogram belongs.

0 **Input data**
ch_x={$peak_1$,$peak_2$,$peak_3$....$peak_N$} – a chromatogram consisting of N peaks
Tr_x=[tr_1,tr_2,tr_3....tr_N] – according to the formula (10)
C_x=[c_1,c_2,c_3....c_N] – according to the formula (11)
N - determines how many classes it can be classified into at the same time

SetOfCH={ch_1,ch_2,ch_3....ch_M} according to the formula (6)
SetOfTr - according to the formula (8)
SetOfC - according to the formula (9)

Output data
SetNoClass – the class number to which the ch_x chromatogram was assigned
SetC - Concentrations of individual fragments occurring in the input vector
1 *R=SetOfTr*Tr_x // R={r_1,r_2,r_3.....r_N} according to the formula (12)*

2 *[RS, Index]=sort(R) // sorting by descending order*

3 *Index=Index(1:M) // obtaining M indices of the elements of the vector R with the largest value*

4 *Class=Index2NoClass(Index)// mapping the element's pattern from the R array to the class number*

5 *SetNoClass =SelectMostFrequentlyOccurringElements(N, Class)// N - determines how many classes it can be classified into at the same time*
6 ***Foreach s ϵ SetNoClass***
SetC(s)= C_x(s) / SetOfC(s) // concentration calculation

End

Algorithm 3. Algorithm for classifying a vector w_x using its chromatogram ch_x where the chromatogram ch_x belongs to single-class or multi-class set.

The algorithm responsible for the classification of chromatograms is presented above. This algorithm consists of several important parts. In the first line 1, the degree of matching of the classified chromatogram to all reference chromatograms is calculated according to the cosine metric. In the next lines, *M* standard chromatograms that best match the tested chromatogram are selected.

In the following lines, the obtained indices to the best-fitting chromatograms are mapped to class numbers, and then the frequencies of occurrences of individual classes are counted.

According to the value of the *N* parameter, the N elements from the Class set that appear most frequently are selected. The *SetNoClass* variable will contain the class numbers that best matched the input chromatogram.

In line 6 of the presented algorithm, the concentration of individual fragments of the input vector is calculated in relation to the standard chromatograms

3.6. Problems of selecting the stationary phase

There are two significant problems when performing calculations using the algorithm presented above. The first problem, which was already indicated in the previous chapter, is related to the selection of the stationary phase in such a way that the chromatograms of vectors belonging to different classes are characterized by different retention times (Leweke, von Lieres, 2018; Pierce et al., 2021; Principle and Procedure…, n.d.). The second problem,

in a sense, is a derivative of the first problem, and is related to the fact that the chromatograms that are created in the process are complex, i.e. they contain a large number of peaks, which makes the classification process difficult by the presented algorithm classifying chromatograms.

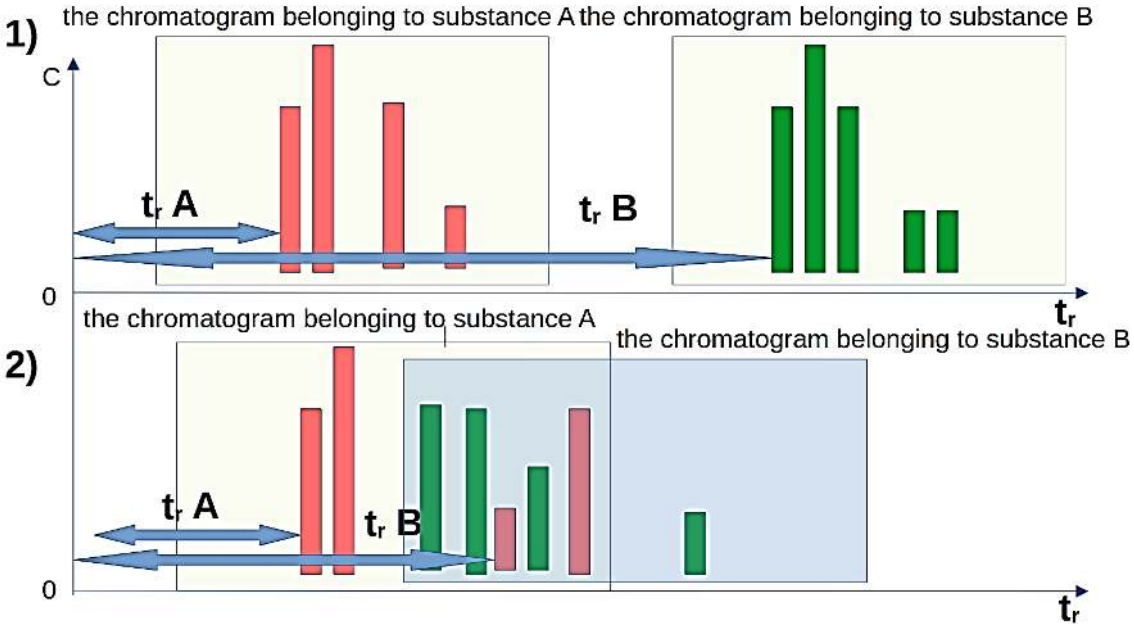

Figure 7. The phenomenon of overlapping retention times.

At this point, an analysis of the functioning of the algorithm will be carried out, taking into account the problem of selecting the stationary phase for a given set of input data vectors, for this purpose the following notations will be introduced (Learning by Simulations…, n.d.).

As the presented formula shows, the scalar product of two vectors is calculated. The more similar the vectors are to each other, the greater the value of the calculated product, the greater the retention time for a given substance. The description of the algorithm and the drawing above show that the correctness of classification is significantly influenced by the distribution of peaks in the chromatogram of the reference substance as well as in the chromatogram of the classified substance. The optimal situation occurs when the distances between individual chromatograms are large or, in other words, the peaks of individual substances do not overlap. The formula describing the distance between the peaks of the chromatogram is presented in formula (13). This formula describes the distance between the i-th and j-th peak.

$$d_{i,j}=\left(tr_i-tr_j\right)^2 \tag{13}$$

Based on the above-mentioned considerations, a criterion for selecting the stationary layer for a given data set can be defined. The structure of the stationary phase - elements of the FS vector should be selected so that for a given data vector the sum of the distances between peaks is the largest, this relationship is expressed by the formula (14).

$$E(fs_1, fs_2, fs_3 \ldots fs_M) = \sum_{i=1}^{N} \sum_{j=i+1}^{N} \square d_{i,j} \sum_{i=1}^{N} \sum_{j=i+1}^{N} \square (tr_i - tr_j)^2 \tag{14}$$

In other words, the elements of the stationary phase should be selected so that the expression described in formula (15) representing the sum of the distances between peaks has the largest value.

$$max\left(E(fs_1, fs_2, fs_3 \ldots fs_M)\right) \tag{15}$$

To find the maximum of the function, the conditions presented in formulas (16), (17) must be met.

$$\begin{aligned} &\frac{\partial E(fs_1, fs_2, fs_3 \ldots fs_M)}{\partial fs_1} = 0 \\ &\frac{\partial E(fs_1, fs_2, fs_3 \ldots fs_M)}{\partial fs_2} = 0 \\ &\ldots \\ &\frac{\partial E(fs_1, fs_2, fs_3 \ldots fs_M)}{\partial fs_M} = 0 \end{aligned} \tag{16}$$

$$\begin{aligned} &\frac{\partial^2 E(fs_1, fs_2, fs_3 \ldots fs_M)}{\partial fs_1^2} < 0 \\ &\frac{\partial^2 E(fs_1, fs_2, fs_3 \ldots fs_M)}{\partial fs_2^2} < 0 \\ &\ldots \\ &\frac{\partial^2 E(fs_1, fs_2, fs_3 \ldots fs_M)}{\partial fs_M^2} < 0 \end{aligned} \tag{17}$$

To simplify further considerations and without losing the generality of the conclusions drawn, suppose the stationary phase consists of two elements M = 2 and the number of substances for which we want to calculate the chromatogram is four N = 4, then the expressions presented above will take the following form:

$$FS = (fs_1, fs_2) \tag{18}$$

$$S = \begin{bmatrix} s_{1,1}, s_{1,2}, \\ s_{2,1}, s_{2,2} \\ s_{3,1}, s_{3,2} \\ s_{4,1}, s_{4,2} \end{bmatrix} \tag{19}$$

$$E(fs_1, fs_2) = \sum_{i=1}^{4} \sum_{j=i+1}^{4} \square d_{i,j} \; d_{1,2} + d_{1,3} + d_{1,4} + d_{2,3} + d_{2,4} + d_{3,4} \sum_{i=1}^{4} \sum_{j=i+1}^{4} \square \{F_{tr}(s_{i,1..M}, FS) - F_{tr}(s_{j,1..M}, FS)\}^2 \tag{20}$$

The function that we maximize for a given input set does not have a maximum. A graph of this function for an example data set is shown below.

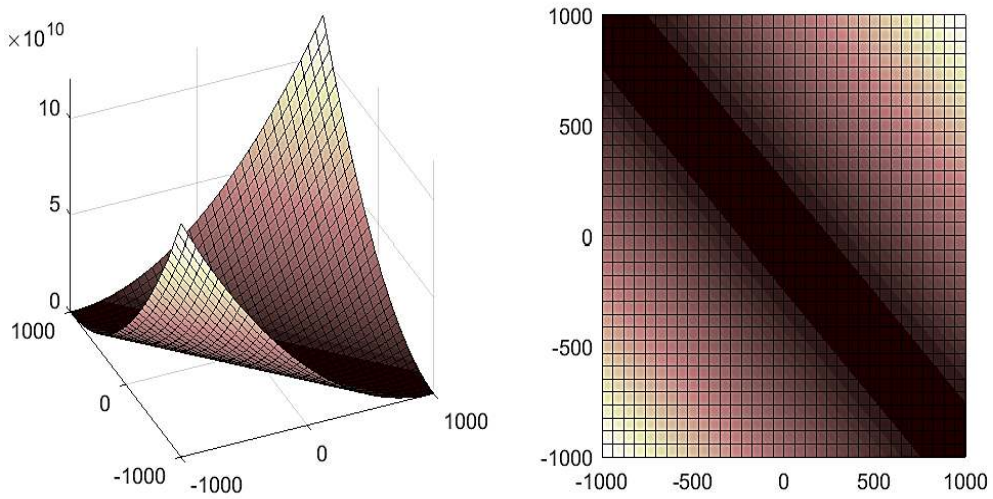

Figure 8. Graph of the maximized function from formula (13) depending on the values of the elements of the stationary phase.

The presented graph shows that the function defined by formula (14) or (20) does not have a maximum in the function responsible for determining the retention time (4), but if the elements of the stationary phase vector have the same sign, the value of function (20) is not limited. This means that the distances between individual peaks will increase proportionally as long as the values of the stationary phase elements increase and if all the stationary phase elements have the same sign. The existence of such a relationship is beneficial, but if we classify highly distorted vectors, the distances between the peaks of the classified chromatogram may differ significantly from the peaks of the chromatogram of the reference vector, which will result in incorrect classification. In this case, replace functions (5) ith a non-linear function.

4. Classification of selected data sets

This chapter will present the classification results for two types of data sets, namely for single-class sets and the second type of classification whose results will be presented is the classification of a multi-class set. Both in the case of the first and the second type of classification, the classification will be performed on files that are in a generally available repository and that were used in the process of testing other classification algorithms. It seems that the above conditions are met by the data sets made available on the UCI Repository website.

The following data sets were selected for the tests. The first set of Thyroid Diseases is related to the medicine and diagnosis of diseases related to the thyroid gland. The remaining two datasets – Landsat and List satellite data – concern image recognition. These datasets were

downloaded from the publicly available UCI Machine Learning Repository (Home – UCI…, n.d.). Detailed information about these datasets is provided. Statistics for the selected datasets are presented in the table below.

Table 1.
Statistics of the test datasets

Data Set	Dimensionality	Number of classes	No of train samples	No of test samples
Thyroid	21	3	3772	3428
Landsat Satellite	36	6	4435	2000
Letters	16	26	15000	5000

All calculations and implementation of individual algorithms were carried out using the MATLAB computing environment.

4.1. Classification of a homogeneous and one-class data set

As can be seen from the presented calculation results, the algorithm presented on sample single-class data sets does not differ significantly from other algorithms. The results achieved are average, but it should be emphasized that these are single-class sets with a very small number of attributes. The classified vectors have 16, 36 and 21 attributes respectively.

Table 2.
Percentage of correct classifications for the Thyroid Disease Data Set (Swiecicki, n.d.)

Algorithm	**%Test**
CART tree	99.36
SSV tree	99.33
MLP+SCG, 4 neurons	99.24
SVM Minkovsky kernel	99.18
MLP+SCG, 4 neurons, 45 SV	98.92
FSM 10 rules	98.90
MLP+SCG, 12 neurons	98.83
Cascade correlation	98.5
MLP+backprop	98.5
SVM Gaussian kernel	98.4
k-NN, k = 1, 8 features	97.3
Naive Bayes	96.1
SVM Gauss, C = 1 s = 0.1	94.7
Chrom	**94.6**
1-NN Manhattan,	93.8
SVM lin, C = 1	93.3

Table 2 shows the classification results of the Thyroid Disease set using the chromatographic algorithm. As shown in the table, the presented algorithm does not differ from other algorithms in terms of classification quality.

Table 3.
Percentage of correct classifications for the Landsat Satellite data Set (Swiecicki, n.d.)

Algorithm	**%Test**
MLP, 36 nodes, +SVNT	91.3
MLP, 36 nodes,	91.0
kNN, k = 3, Manhattan	90.9
FSMneurofuzzy, learn 0.95	89.7
kNN, k = 1, Euclidean	89.4
SVM Gaussian kernel	88.4
RBF, Statlog result	87.9
Chrom	**87.8**
MLP, Statlog result	86.1
Bayesian Tree	85.3
C4.5 tree	85.0
SSV tree	84.3
Cascade	83.7
LDA Discrim	82.9
Kohonen	82.1
Bayes	71.3

Table 3 shows the classification results of the Landsat Satellite data Set using the chromatographic algorithm. Similarly to the previous case. As can be seen from the table presented, the presented algorithm does not differ from other algorithms in terms of classification quality. In order to improve the quality of classification in this case, it would be necessary to consider changing the level of fragmentation (Algorithm 1**.**).

Table 4.
Percentage of correct classifications for the Letter Recognition Data Set (Swiecicki, n.d.)

Algorithm	**%Test**
Chrom	**94.10**
ALLOC80	93.60
K-NN	93.20
LVQ	92.10
Quadisc	88.70
CN2	88.50
Bayesian Tree	87.60
NewId	87.20
IndCART	87.00
C4.5	86.80
DIPOL92	82.40
RBF	76.60
Logdisc	76.60
Kohonen	74.80
Backprop	67.30

In the case of classification using the Letter, the presented algorithm turned out to be the best.

The sets from the point of view of the presented algorithm are not well selected - because they have relatively few attributes, but there is a large set of publications presenting the results of the classification of these sets using various classification algorithms.

4.2. Principle of multiclass vector classification

The basic property of the presented algorithm is the ability to classify data containing data from several classes at the same time, i.e. the so-called multi-class vectors. To illustrate this case, assume that we have a vector containing data belonging to two classes, e.g. data belonging to class 1 and class 2. Then the chromatogram of such a vector will look as shown in Figure 9.

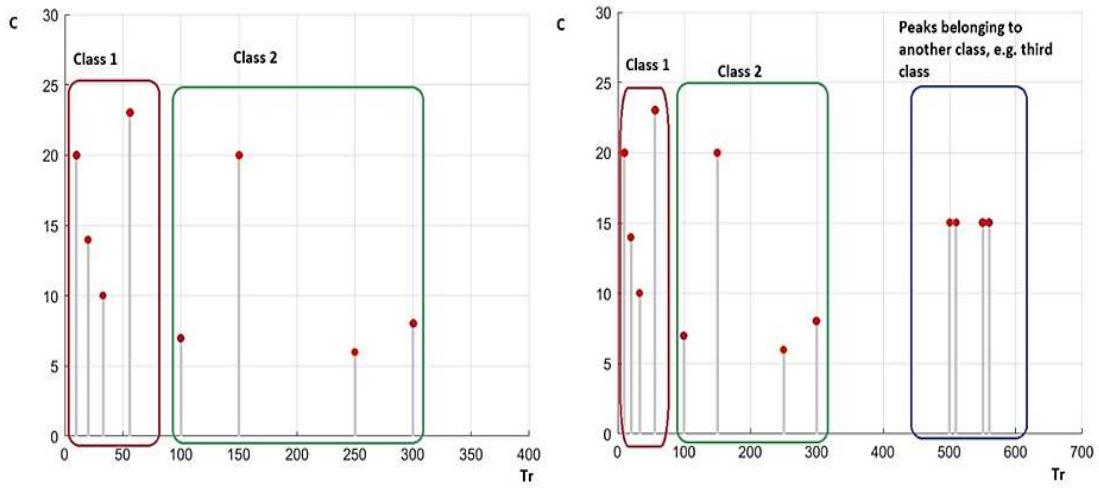

Figure 9. Chromatograms of vectors belonging to a) two classes: b) to three classes.

As can be seen from the figures presented, the chromatograms contain peaks specific to chromatograms belonging to class 1 and class 2. After adding peaks that belong to class, e.g. class 3, we do not lose information about peaks belonging to classes 1 and 2. All peaks should be correctly identified.

Thanks to the proposed data processing technique, it is possible to classify cases in which the classified vector belongs to several classes at the same time.

4.3. Classification of multi class vectors

Using the letter data set, a multi-class set was created - one contains fragments belonging to five classes. The task of the algorithm was to answer the question into what classes a given input vector could be classified.

This means that a given input vector may contain any combination of data for classification, which may belong to a given number of classes. For a single class, it contains pieces of data that may belong to a single class. However, if the number of classes is equal to two, then the input vector that was processed by algorithm 1 may contain data that may belong to at most two classes.

Table 5.
Classification results using a multi-class set chromatographic algorithm

Fragmen-tation	Number of Classes									
	1		2		3		4		5	
	NoClass	C	NoClass	C	NoClass	C	NoClass	C	NoClass	C
16	92.4	92.4	73.3	70,2	47.9	44,2	26.7	24.7	11.5	10.1
8	90.4	90.4	70.3	68.4	45.9	40,4	25.7	21.7	10.0	8.2
4	89.4	89.4	69.3	65.1	44.9	40.0	24.7	20.4	9.8	7.3

Table 5 presents the classification results of a multi-class set created from the Letter set. The presented results show the percentage of correct classifications. Each column related to the number of classes has been divided into two columns - the first column called *NoClass* - gives the percentage correctness of the classification in terms of quality, i.e. whether fragments belonging to the appropriate classes have been correctly identified in a given input vector. The second column called *C* - concentration informs how many of these fragments have been correctly identified, i.e. it provides quantitative information

$$C_{CorrectPercent} = 100 \cdot \left(1 - \frac{\left| \sum_{i=1}^{NumberOfClass} C^{out}{}_i - C^{pattern}{}_i \right|}{\sum_{i=1}^{NumberOfClass} C^{pattern}{}_i}\right) \tag{21}$$

In order to assess the correctness of the classification in quantitative terms, an indicator was defined that was used to evaluate this type of classification. This indicator is presented using a formula. The $C_{pattern}$ vector contains information about the actual number of vector fragments in the vector that is subjected to the classification process. Whereas the C_{out} vector contains information about the number of vector fragments identified by the classifier. The $C_{CorectPercent}$ indicator gives the percentage of correct classifications for a given input vector out of the number of fragments of subvectors belonging to particular classes - i.e. concentrations.

As the table shows, providing quantitative information is less accurate compared to the situation when we evaluate the classifier in qualitative terms.

As the results presented in the table show, the presented algorithm correctly identified three classes - the percentage of correct answers was over fifty percent. However, when indicating the remaining classes to which fragments of the input vector belong, the number of correct answers was no longer satisfactory.

Nevertheless, it should be noted that the difference between the correct answers of the quantitative classifier and the qualitative answers of the classifier was not that large – it was several percentage points, and the classifier provided quantitative information, which is quite important in various decision-making processes.

5. Conclusions

The article presents an innovative method of data processing similar to chromatographic data separation in analytical chemistry. Three algorithms have been proposed, the aim of which is to convert the data vector into a set of mixtures and classifications of individual chemical substances, which was created in the process of transforming the input vector. The paper presents results for well-known sets such as Thyroid, Landsat Satellite and

Letters. As shown, this data classification technique will be suitable for multi-class sets, i.e. those containing fragments in which vectors contain fragments of data belonging to several classes at the same time. The work also shows that using the proposed algorithms it is possible to obtain information about the classified vector not only of a qualitative nature, but also that the presented classification technique provides quantitative information.

The article presents an algorithm for the separation of chromatographic data, which was inspired by one of the methods of analytical chemistry, which is resolution chromatography. Three algorithms were proposed for chromatographic data separation, which constitute the chromatographic data separation process. Algorithm 1, whose task is to transform a set of input vectors into a set of mixtures of substances. Algorithm 2, the algorithm responsible for calculating the retention time. The third algorithm is responsible for assigning the spectrum of the unknown substance, i.e. the input vector, to the chromatograms of the reference vectors. As shown in all the above-mentioned types of datasets, the proposed classification mechanism performed relatively well. In order to improve the classification efficiency of the presented mechanism, it would be necessary, first of all, to algorithmize the problem of stationary phase selection taking into account nonlinear functions.

Based on the presented results, it can be assumed that the chromatographic data separation technique can be successfully used in the processing of large data sets, where the data do not always have such features as a constant vector length, a relatively small number of elements in the vectors and are heterogeneous.

References

1. Blumberg, L.M. (2021). Theory of gas chromatography. *Gas Chromatography*, pp. 19-97. Retrieved from: https://doi.org/10.1016/B978-0-12-820675-1.00026-5.
2. Brabazon, A., O'Neill, M., Mcgarraghy, S. (n.d.). *Natural Computing Series Natural Computing Algorithms*. Retrieved from: www.springer.com/series/, 6.02.2024.
3. Giddings, J.C. (2017). Dynamics of chromatography: Principles and theory. *Dynamics of Chromatography: Principles and Theory*, pp. 1-323. Retrieved from:

https://doi.org/10.1201/9781315275871/DYNAMICS-CHROMATOGRAPHY-CALVIN-GIDDINGS.

4. Hage, D.S. (1999). *Affinity Chromatography: A Review of Clinical Applications*. Retrieved from: https://academic.oup.com/clinchem/article/45/5/593/5643177.
5. Hilbert, M. (2016). Big Data for Development: A Review of Promises and Challenges. *Development Policy Review*, *34(1)*, pp. 135-174. Retrieved from: https://doi.org/10.1111/DPR.12142.
6. Hohrenk, L.L., Itzel, F., Baetz, N., Tuerk, J., Vosough, M., Schmidt, T.C. (2020). Comparison of Software Tools for Liquid Chromatography-High-Resolution Mass Spectrometry Data Processing in Nontarget Screening of Environmental Samples. *Analytical Chemistry*, *92(2),* pp. 1898-1907. Retrieved from: https://doi.org/10.1021/ACS.ANALCHEM.9B04095/ SUPPL_FILE/AC9B04095_SI_001.PDF.
7. *Home – UCI Machine Learning Repository* (n.d.). Retrieved from: https://archive.ics.uci.edu/, 3.06.2024.
8. *Learning by Simulations: Overlapping Peaks* (n.d.). Retrieved from: https://www.vias.org/simulations/simusoft_peakoverlap.html, 6.02.2024.
9. Leweke, S., von Lieres, E. (2018). Chromatography Analysis and Design Toolkit (CADET). *Computers & Chemical Engineering*, *113*, pp. 274-294. Retrieved from: https://doi.org/10.1016/J.COMPCHEMENG.2018.02.025.
10. Pezzatti, J., Boccard, J., Codesido, S., Gagnebin, Y., Joshi, A., Picard, D., González-Ruiz, V., Rudaz, S. (2020). Implementation of liquid chromatography–high resolution mass spectrometry methods for untargeted metabolomic analyses of biological samples: A tutorial. *Analytica Chimica Acta*, *1105*, pp. 28-44. Retrieved from: https://doi.org/10.1016/J.ACA.2019.12.062.
11. Pierce, K.M., Trinklein, T.J., Nadeau, J.S., Synovec, R.E. (2021). Data analysis methods for gas chromatography. *Gas Chromatography*, pp. 525-546. Retrieved from: https://doi.org/10.1016/B978-0-12-820675-1.00007-1.
12. *Principle and Procedure of Affinity Chromatography* (n.d.). Retrieved from: https://whatishplc.com/hplc-basics/affinity-chromatography/, 6.02.2024.
13. Reinsel, D., Gantz, J., Rydning, J. (2017). *Data Age 2025: The Evolution of Data to Life-Critical Don't Focus on Big Data; Focus on the Data That's Big.* Sponsored by Seagate. Retrieved from: www.idc.com.
14. Robards, K., Ryan, D. (2021). Principles and Practice of Modern Chromatographic Methods. *Principles and Practice of Modern Chromatographic Methods*, pp. 1-518. Retrieved from: https://doi.org/10.1016/B978-0-12-822096-2.09993-X.
15. Stilo, F., Bicchi, C., Jimenez-Carvelo, A.M., Cuadros-Rodriguez, L., Reichenbach, S.E., Cordero, C. (2021). Chromatographic fingerprinting by comprehensive two-dimensional chromatography: Fundamentals and tools. *TrAC Trends in Analytical Chemistry*, *134*, *116133*. Retrieved from: https://doi.org/10.1016/J.TRAC.2020.116133.

16. Swiecicki, M. (2009). An algorithm based on the construction of Braun's cathode ray tube as a novel technique for data classification. *Neutral Information Processing, Vol. 5864 LNCS, Iss. PART 2,* pp. *710-719*, *5864 LNCS* (PART 2). Retrieved from: https://doi.org/10.1007/978-3-642-10684-2_79.
17. Święcicki, M. (2024). A Classification Algorithm Inspired by the Chromatographic Separation Mechanism Dedicated to the Classification of Variable-length and Multi-class Vectors. *JOIV: International Journal on Informatics Visualization*, *8(1)*. Retrieved from: https://doi.org/10.62527/JOIV.8.1.2324.
18. Urh, M., Simpson, D., Zhao, K. (2009). Affinity chromatography: general methods. *Methods in Enzymology*, *463*(C), pp. 417-438. Retrieved from: https://doi.org/10.1016/S0076-6879(09)63026-3
19. Varhadi, S.D., Gaikwad, V.A., Sali, R.R., Chambalwar, K., Kandekar, V. (2020). *A Short Review on: Definition, Principle and Applications of High Performance Liquid Chromatography. Introduction, 19*(2), pp. 628-634. Retrieved from: www.ijppr.humanjournals.com
20. Witting, M., Böcker, S. (2020). Current status of retention time prediction in metabolite identification. *Journal of Separation Science*, *43(9-10)*, pp. 1746-1754. Retrieved from: https://doi.org/10.1002/JSSC.202000060.

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ONLINE MERCHANDISING – TOOLS, CONDITIONS, AND RESULTS

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Purpose: To present the essence of modern online merchandising (in light of literature studies and the author's own research), demonstrate examples of its tools, methods, and procedures, and develop recommendations for interested marketers.
Methodology: analysis of secondary sources of information, analysis of the services of specialised agencies offering support in methodical online merchandising activities, case studies of selected online stores from various economic sectors (grocery, food, clothing, cosmetics, footwear, hardware, home furnishings, pharmaceuticals, automotive, bookstores) with participant observation, and involvement of students in the evaluation of the level of online merchandising activities of these sites.
Findings: Instruments, determinants, and directions of development of methodical online merchandising activities aimed at stakeholder experience management taking into account contemporary trends and conditions and the results obtained.
Research limitations: The article is based on literature studies, selected web resources (specialised agency websites, thematic blogs, and other thematically related publications), case studies of selected online stores from different economic sectors, own participant observation, and involvement of young people (marketing students) in the analysis and evaluation of online merchandising practices of selected traditional and modern retail facilities. The research problem addressed should be analysed based on a larger number of online stores. Moreover, the next project also plans to survey the opinions of online store owners and companies supporting the development and implementation of online merchandising strategies, and conduct representative surveys of actual customers of the analysed retail facilities.
Practical implications: Systematising knowledge and identifying contemporary online merchandising instruments. Implementation of methodical activities in the analysed area with the involvement of stakeholders (including in particular: online store owners, partner companies, and customers). Actually enhancing the online shopping experience, ensuring multifaceted benefits for all those involved, reducing the burden of resource exploitation in the e-commerce process with reference to traditional commerce, engaging stakeholders and personifying activities, adapting activities to conditions, managing the experiences of e-commerce participants, building a real and virtual community.
Social implications: Research shows that online merchandising activities/actions/campaigns do impact customer behaviours, their experiences, attitudes, engagement, changes in the ways of buying and using products, marketer practices, and – consequently – the entire society and natural environment. They also lead to the promotion – under the brand and with the engagement of its stakeholders – of a sustainable approach to resource management and undertaking projects in line with the 2030 Agenda and recommendations of the ESG directive.

Value: It is the first study of this type (at least in the Polish market) regarding the impact of methodical online merchandising activities on the experiences of key stakeholders and the resulting practical implications (social, economic, environmental, and managerial).
Keywords: online merchandising, digitalisation, always online consumers, creating customer experiences in an online store.
Category of the paper: research paper.

1. Introduction

Having to cope with social (Gajewski, 1997; Foxall, Goldsmith, 1998; Zaltman, 2003; Clatworthy, 2022; Tracy, 2023;), competitive (Wilk, 2014; Chaffey, Smith, 2017; Berkhout, 2019; Brzustewicz, 2023; Wolniak, Grebski, 2023; Wrzesińska-Kowal, 2024), technical (Tarczydło, 2015; Jak korzystamy…, 2024; Martinez-Lopez et al., 2024), technological (Levy, 2021; Troian, 2023; E-commerce w Polsce, 2024; Foster, 2024) and managerial (Keller, 2013; Kotarbiński, 2021; Kotler et al., 2021) conditions as well as trends (United Nations, 2015; Wan et al., 2016; Egorova et al., 2022; Kamiński, 2022; Chojan, 2023; Florczak, 2023; Ghaffar et al., 2023; Wolniak et al., 2023; Polski rynek e-commerce…, 2024), marketers try to implement various measures to support sales and generate multifaceted benefits for parties involved. The following study analyses online merchandising (a set of activities related to the arrangement of an online shop and the effective presentation of its offer tailored to the current market conditions) as an important trend in the management (Cox, Brittain, 2000; Levy, Weitz, 2004; Williams, Mullin, 2011; Wojciechowska, 2020) of online shops (Ebster, Garaus, 2011; Feldy, 2012; Sklepy przyszłości…, 2018; Sklepy internetowe…, 2024), the need to streamline their operations, personalise their offer and the growing expectations of digitised and digitalised customers (Wilk, 2015; Tarczydło, Miłoń, 2019; Troian, 2023; Foster, 2024; Kocot, Maciaszczyk, 2024; Wolniak, 2024) that are always online. All parties (Campbell, 2020; Kotler et al., 2021; Targiel, 2022) involved (online shop owner, operating staff, customers, partners and other entities) shall gain multifaceted benefits from online merchandising initiatives as an important phenomenon in modern management (Chaffey, Smith, 2017; Hansen, 2021; Troian, 2023) and in the era of dynamic e-commerce development.

This article aims to introduce the essence of modern online merchandising, present examples of such practices (tools, methods and procedures) and develop recommendations for marketers interested in it. For this article, a literature study, a meta-analysis of available online sources and qualitative in-house research were carried out using the following methods: multiple case studies (how online merchandising activities are carried out by selected online shops, how they interact with stakeholder experiences and what impacts they generate), participant observation and online content analysis.

2. Literature review

Online merchandising (also known as e-merchandising or web merchandising) constitutes a set of activities related to the art of arranging an online shop, presenting its offer and individual products in such a way that it meets customers' expectations (Tarczydło, 2005; Diamond, Diamond, 2007; Witek, 2007; Morgan, 2008; Borusiak, 2009; Binsztok, Zuzański, 2013; Garrido-Morgado, Gonzalez-Benito, 2015; Russel, 2015; Borusiak, Wanat, 2020; Bailey, Baker, 2022; Morgan, 2022; Czym jest merchandising…, 2024; Tobała, 2024). This is a range of techniques in the field of marketing, which includes: management of the shop's offer and the way it is presented; the category management method, the use of display techniques; use of knowledge about the psychology of perception and skillful influence on the online shop visitor; adaptation to current conditions, e.g. having virtual fitting rooms, and many others.

From a process perspective (Russel, 2015; Tarczydło, 2015; Wu et al, 2015; Trendy w visual merchandising…, 2024), online merchandising is the process of creating, maintaining and developing the unique character of an online shop that distinguishes it from its competitors, supported by other marketing measures (systematic market research, attractive product and pricing policies; unique promotional and supporting marketing communication measures).

According to Rafał Cyrański (2024), and it is reasonable to agree with his opinion, in order to effectively use the new trends in e-commerce (Raport e-commerce…, 2021; Kocot, Maciaszczyk, 2024; Polski rynek e-commerce…, 2024) merchandising to increase sales, several important principles must be followed. First of all, it is important that the online shop is easy to navigate and provides users with an intuitive experience. Providing users with quick and easy access to products and services can significantly increase the number of potential customers. Second, it is important that the online shop offers attractive promotions and discounts. Promotions can be applied in various ways, such as price reductions or free shipping. This can encourage customers to make a purchase. Thirdly, the application of personalisation techniques for marketing content, tailored to individual customer needs, is also essential. As a result, the products or services can be matched more closely to the customer's actual expectations and needs, thereby increasing the chances of selling.

In other words, online merchandising should enable an optimal access to products and services in order to overcome the barrier of the lack of direct contact with the transaction object, and to make the shopping experience easier and more enjoyable by i.a. good navigation on the shop's website, additional attractions – promotions and discounts, or personalised (Levy, 2021; Lubin, 2022; Kapelczak, 2024; Foster, 2024) content. The online merchandising projects/actions implemented are meant to positively surprise and differentiate from the competition. Creative activities evoking emotions (Skowronek, 2014; Tarczydło, 2014), creating e-commerce brand experiences (Smilansky, 2009; Schmitt, 2011; Ind, 2016; Tarczydło, 2016; Tarczydło, Miłoń, 2019; Wojciechowska, 2020; Foroudi, Palazzo, 2021;

Ghaffar et al., 2023; Larsen, 2023; Tarczydło, Miłoń, Klimczak, 2023), perfected down to the smallest detail hit stakeholder (Campbell, 2020; Tracy, 2023; Kocot, Maciaszczyk, 2024; Wolniak, 2024) expectations accurately. The undertakings carried out are intended to touch customers by drawing their attention, interest, willingness to take advantage and active participation. The experience or sensations gained should affect emotions, move, evoke feelings, but also provide rational arguments and, as a consequence, trigger some kind of measurable reaction towards the online shop brand.

In business practice, online merchandising ventures involve employees and other parties: partners, Internet users, media representatives, the online community, competitors, although they are usually targeted at customers. Hence, it brings multifaceted benefits for all parties involved.

The elements of human behavioural psychology (Underhill, 2001; Zaltman, 2003; Feldy, 2012; Binsztok, Zuzański, 2013; Clatworthy, 2020; Tracy, 2023; Kapelczak, 2024) versus effective e-merchandising constitute a relevant topic. In order to design effective online merchandising activities, it is crucial to be aware of the behaviour of the buyers one wishes to influence. The behaviour of buyers represents the totality of activities related to the acquisition, use and disposal of products, together with the decisions that precede and condition these activities (Gajewski, 1997; Zaltman, 2003; Tarczydło, 2005).

In marketing (Kotler et al, 2021), there are many theories and models (Foxall, Goldsmith, 1998; Smilansky, 2009; Zaltman, 2003) about buyer behaviour at the point of sale that can be adapted for e-commerce. These models illustrate the great role that the environment in which the product is offered plays in the customer's decision-making process.

The simplest model indicating the need for promotional activities in the selling unit is the SLB (Stay, Look, Buy) model. The AIDA model seems to be the most common model. It is an acronym for: Attention – to attract attention, Interest – to arouse interest, Desire – the desire to possess, Action – action, purchase. The model reflects the reality that capturing consumers' attention and arousing their interest in a product triggers a need for possession and, consequently, a purchase. Another model is AIDCAS (Attention, Interest, Desire, Conviction, Action, Satisfaction). This is a formula compatible with current market conditions. It requires a great deal of skill to select the means and methods of merchandising activities in a particular sales unit in such a way that the customer is able to go through the various phases of the indicated model and, consequently, loyally return and purchase.

Successful influence on the buyer depends on his perception, i.e. the process of recognising, selecting, organising and interpreting stimuli in order to make sense of the surrounding reality (Tarczydło, 2014; Targiel, 2022; Troian, 2023). Perception takes place through the senses – sight, touch, hearing, smell and taste. The factors influencing perception can be reduced to two categories. The external group of factors consists of the stimuli that affect the person, while the second category concerns the internal conditions of the person and his or her individual characteristics. Stimulus factors are related to physical characteristics of the perceived objects

such as size, colour, shape, weight, etc. Size directly determines the strength of the stimulus. Thus, it is perhaps the most prominent feature that sets it apart from its surroundings.

The modern world sends out numerous signals (stimuli). Everyone perceives external information differently. People pay attention only to stimuli that they consider relevant to their needs, desires, beliefs and attitudes (Jak korzystamy…, 2024). An important clue for online merchandising measures may be the fact that people's attention is especially attracted by information that is not fully explicit as well as surprising (Dudka, 2024). Curiosity drives people into action. Salespeople deploy all sorts of tricks to get the customer's attention.

People show a high selectivity in the perception of information (so-called filtering perception), mainly due to the limited perceptive capacity of the individual senses and the limited capacity of consciousness. It is believed that a person can assimilate at most 6-7 separate pieces of information (Tracy, 2023) at the same time. Thus, only a small part of the information reaching a person is noticed and remembered, thereby becoming an internal source of information. Any other information is suppressed, ignored or discarded. As well as being subject to selective perception and memory, signals are often distorted and inconsistent with reality. Examples include increased feelings of hunger influenced by tasteful images and pictures of appetising products, or the limits of promotional offers, which arouses the desire to get the attractive offer. Although in both cases there were no physical changes that would explain the increase in hunger or the change in the hierarchy of needs - the client behaves differently. A great deal of this type of behaviour is leveraged by online merchandising (Borusiak, Wanat, 2020; Bailey, Baker, 2022; Morgan, 2022; Cyrański, 2024; Czym jest merchandising…, 2024; Dudka, 2024; Tobała, 2024; Trendy w visual merchandising…, 2024), which generates a range of stimuli.

The subconscious, which also registers certain stimuli, is often utilised in the perception process. This is known as subliminal perception (Zaltman, 2003; Jak korzystamy…, 2024). The problem of subconscious perception, i.e. perceiving stimuli and reacting to them beneath a certain perceptual threshold (subconscious threshold), is often addressed in the marketing psychology literature. It raises a number of controversies. For ethical reasons, the use of subconscious perception is often prohibited when developing marketing messages. The perception process is further complemented by emotions and patterns memorised from the past.

Perception can also be formed through pleasant associations, creating a mood and atmosphere conducive to shopping. This can be done using, for example, appropriate colours, changing backgrounds and other available stimuli (Skowronek, 2014; Tarczydło, Miłoń, 2019; Wolniak, 2023).

The second group of factors influencing perception is related, on the one hand, to a person's somatic (bodily) characteristics (e.g. human body structure, defects in the sense organs) and the state of his or her body (e.g. fatigue, illness, hunger) and, on the other hand, to one's psychological characteristics, inclinations, expectations, the conditions in which one

uses the online shop's offer and even the device with which one makes the transaction, etc. (Foxall, Goldsmith, 1998; Binsztok, Zuzański, 2013). Factors related to the structure of the human organism (bodily characteristics, state of the organism) do not have as great impact as the external factors of a 'stimulus' nature described earlier.

The perception of stimuli causes specific buyer behaviour according to the model (Tracy, 2023): stimulus – reaction – organism (photo, look, interest; product presentation, interest, close inspection). In practice, purchasing decisions are influenced by a complex of determinants, including, among others, reflection time.

The biggest opportunity for online merchandising comes from impulsive decisions (Ebster, Garaus, 2011; Dudka, 2024). In business practice, the following occur: real impulses, someone did not plan to buy, but bought, e.g. because of a promotion; unreal impulses, someone was supposed to buy a product, e.g. shoes, a dress, a gift, but did not know what type, brand and chose a particular good, e.g. because of a good display in an online shop or thanks to the use of additional stimuli, hints of 'others also bought.

There is no consensus among authors in the information sources available on the scope of online merchandising activities (Diamond, Diamond, 2007; Witek, 2007; Morgan, 2008; Borusiak, 2009; Binsztok, Zuzański, 2013; Garrido-Morgado, Gonzalez-Benito, 2015; Russel, 2015; Borusiak, Wanat, 2020; Bailey, Baker, 2022; Morgan, 2022; Czym jest merchandising…, 2024; Tobała, 2024) and measures. Furthermore, merchandising is an area of marketing tools that theoreticians learn from practitioners, hence the need to deepen knowledge in this area.

3. Own research methodology

The research gap revealed concerns the scope and methodological considerations of online merchandising activities. For the purpose of this article, a qualitative self-study was carried out using the following methods: multiple case study (aimed at answering questions: How are the online merchandising activities of the selected online shops carried out? What do they cover? How do they interact with the addressee, their senses, mind and heart and with other stakeholders? How do they engage, what experiences, behaviours and attitudes do they create? What effects do they generate? What lessons can be learned based on them? Participatory observation and online content analysis. The following research scopes were defined: temporal: November 2023 – March 2024; subjective: active internet users, observers; objective: ways and forms of online merchandising of the analysed shops; and spatial scope: websites, online and traditional shops, in other available channels.

Based on a review of the available literature and online sources, the own research was carried out for the purpose of the article. These included analyses/case studies combined with participant observation in selected online shops (grocery, food, clothing, cosmetics, footwear,

hardware, home furnishings, pharmaceuticals, automotive, bookstores). The results of the observations were referred to available literature sources as well as our own experience of using merchandising in business practice. For more than a dozen years, the author has been involved in developing and implementing merchandising strategies for companies, including online merchandising, i.a. from the following industries: grocery, food, clothing, footware, paints and varnishes and construction. She also holds classes in Merchandising (a specialisation subject in the Management course), Online and Offline Merchandising (an elective subject) and training workshops for practitioners.

The aim of the research was to obtain information on the tools, methods and procedures of online merchandising activities, while taking into account the specific characteristics of the industry. The research was conducted in selected online shops, at point-of-sale and tablet desks with access to the wider offering, among partners where the author was involved in implementing merchandising strategies, at industry events on e-commerce and online marketing. The research included also systematic participant observation, case studies of selected market players owning and developing online shops. The author carried out a qualitative analysis of the resources acquired (photos, handouts, videos). She paid particular attention to ways of creating opportunities for unique experiences for online shopping customers through appropriate display of the products on offer, other tools and procedures applied and their resonance and results.

4. The online merchandising toolbox developed

From the perspective of several years of observing merchandising activities in various economic sectors, personal involvement in the strategies developed and solutions created (shop layout, atmosphere, display techniques, supporting measures...), as well as the high dynamics in the development of e-commerce and the need to organise increasingly functional and attractive online shops, there is a clear tendency to diversify them, adapting them to technological progress, changing consumer expectations and legal, environmental and competitive conditions.

Therefore, based on the results of conducted literature and empirical research (analysis of selected online shops from the point of view of applied activities in the analysed area), they provide a basis for a broad understanding of online merchandising efforts. Complex thinking and acting in the area discussed should, according to the author, take into account the following elements:

- well-considered choice of the ‘location’ of the online shop, in other words, its appropriate positioning on the web and SEO and SEM marketing activities for it,
- taking care of publishing content so that active leads can be acquired and the potential customer is redirected to the online shop, e.g. from the company blog or from the brand’s social profiles,
- design of the shop’s website tailored to the circumstances and ‘up to date’ possibilities,
- informing about special occasions,
- making reference to significant events from the lives of visitors and from the local environment,
- sales assortment and its clear presentation as well as assistance in finding what the customer is interested in,
- category management (which, in a nutshell, consists of dividing up the assortment on offer and displaying the products in such a way as to facilitate customer purchases, while optimising the results of the trader and manufacturer),
- a clear layout of the site using techniques to attract the visitor’s attention, e.g. by locating the image in a central visual point or using ‘call to action’ buttons,
- responsive shop websites adapted to mobile phones, computers and other devices from which users enter the online shop, browse the offer and make purchases or leave the shop,
- intuitive shop interface,
- ability to navigate the site smoothly (seamless switching between different devices),
- shaping the climate (colours, shapes, lighting, metaphorical smells and tastes...),
- specialised themed arrangements,
- presentation of the products on offer in such a way that their qualities can be seen,
- additional content,
- convenient payment systems,
- virtual fitting rooms and other shopping support systems/solutions (e.g. functionality for measuring the foot before purchasing shoes),
- management of the sales assortment in terms of its range, introduction of new products, adaptation of the offer to customers’ expectations,
- possibility to customise the product with configurators,
- designation of active and passive zones, i.e. where the exposure will be best and worst seen,
- application of specialised display techniques (e.g. open display, rich display, total display, brand presence, themed display, series display, block display, amphitheatre display, quality display, cross merchandising),

- matching price information with the results of market research and the psychology of human behaviour (e.g. the formation of price lines, the determination of basic price zones and the use of psychological pricing),
- developing an annual list of promotional campaign themes around which thematic arrangements will be organised and which are important and interesting for people using the online shop's offer,
- concern for the climate of the commercial unit, i.e. the set of factors that directly affect human well-being (including influencing the senses of sight, taste, hearing, smell, touch and 'business acumen' through appropriate temperature, lighting, colours, music, smell, etc.),
- design of online merchandising concepts and/or planograms, i.e. templates for displaying products in tabs and shop windows,
- organising a virtual shop corresponding to a traditional one,
- matching the type of online merchandising strategy being pursued, whether by the manufacturer, retailer or joint unit owner, taking into account both the interests of the manufacturer, the retailer and the convenience of the customer,
- training of staff involved in implementing online merchandising solutions,
- planning a schedule of activities, including who is responsible for what, when and who coordinates it,
- permanent analysis of the behaviour of people using e-commerce and the competitors' actions, according to the principle that those who are creative, can surprise and can make a spectacle out of sales, thus providing additional value to customers, win,
- developing tools and methods to measure the effectiveness of the applied actions (e.g. having appropriate software that records the volume of sales and indirectly gives the possibility to analyse the effectiveness of the applied display techniques, 'tracks' the behaviour of online shop visitors and when they want to leave the shop it generates additional stimuli, e.g. subscribe to a newsletter and receive a 5% discount),
- application of available digital solutions to support the management of the online shop, such as electronic loyalty cards, mobile loyalty apps, electronic price labels ESL (Electronic Shell Labels), which work with a central management server and allow flexible price changes according to time, hour or type of customer; eViator electronic shopping cart to help track the path of a customer who does not hold a loyalty card or mobile app; innovative billing systems...

Apart from the aforementioned areas of activity, appropriate supporting measures are of great importance, i.e. encouraging the customer to visit the online shop, e.g. by publishing content that enables redirections or by clearly indicating the name or logo. Use of specialised display techniques, e.g. presentation of the product on a virtual persona, preparation of additional promotional measures, e.g. graphic signs, colour coding, additional information

material, etc. Complex online merchandising activities provide wide-ranging benefits for the parties involved, i.e. the retailer, the manufacturer and the customers.

As a conclusion, it is assumed that the methodical practices of online merchandising are well-thought-out activities; the process of generating incentives that influence the addressees; creating opportunities to learn about the offer and additional attractions.

E-merchandising managers emphasise the importance of so-called 'touchpoints', i.e. broad opportunities for interaction, e.g. visiting a website, seeing an advert, visiting a shop, talking to a virtual customer adviser, entering a competition, using a mobile app, etc.

Finally, it is important to determine the so-called *customer journey*, i.e. all the elements that make up the sum of the interactions taking place in contact with the branded market player, from the initial contact through all stages of interaction (using the offer), including possible potential interactions, including post-sales service and the marketing tools used, e.g. the loyalty card or other forms of lead nurturing.

In addition to the customer journey, the *experiential selling proposition* is also important, and this is reflected in the ability to associate certain emotions and experiences that translate into value and experiences with an online shop, usually a shop of a particular brand. Emphasis should also be put on the significance of contemporary conditions (social, technical-technological, economic, competitive, environmental and other) determining the effectiveness of the issues and practices under consideration. In the era of social media and the prevalence of sharing knowledge and experiences with other members of the community with whom we are in contact and the willingness of prosumers to engage with providers, the art of designing the layout of an online shop's interior and displaying its offerings appropriately has taken on particular importance.

Furthermore, one can conclude that online merchandising is still a new and complex topic and that the research being discussed should help marketers to better understand the perspective of consumers and other stakeholders and to approach these practices methodically, which seems to be necessary due to technological advances, the development of web functionality and the pressure for changes in e-commerce.

To summarise, in view of the research conducted, the spectrum of online merchandising activities, is both impressive and desirable. Tools, methods and procedures of the practices discussed are of great importance in e-commerce, but also resonate with activities in traditional distribution models and are expected by customers, but also by online shop managers. They generate many benefits for all involved, for the environment, for the planet.

5. Conclusions and recommendations

Given the current market conditions, including the rapid growth of e-commerce, merchandising is developing very fast. The reason for this is the ability to replicate ready-made Western models (without the need to develop new strategies), and the high absorptive capacity of the market. The changes in e-commerce are clearly visible and striking. Nevertheless, there is still a huge gap between the available online shops, which, fortunately, is not the rule. One thing that is unequivocal is that customers are increasingly demanding and the appropriate product range is no longer enough. There is a clear need for continuous improvement of the sales conditions, which is reflected in the survey results. The Centre for Public Opinion Research says that Poles are increasingly satisfied with e-commerce. When buying, they are guided by shopping convenience, low prices, frequent promotions and advice from sellers.

Another argument stimulating efforts in the analysed area is the fact that international corporations have been using comprehensive online merchandising activities for a long time, therefore domestic entrepreneurs should not neglect these activities either, if they want to meet the standards of competition.

The literature studies and own research carried out provided information on the instrumentarium of online merchandising and related issues, i.e. its strategy, persons in charge, specialist agencies, conditions and trends, supporting tools, expectations of stakeholders (especially traders and customers), development directions and legal aspects.

To summarise, the literature studies and practice observations show that methodical online merchandising activities are an essential element of successful online sales management. Every organisation, be it a manufacturer or retail entity owner, should strive to develop an online merchandising strategy for its own brand, product range or shop to optimise the effects of virtual shelf management and to adapt as much as possible to the current expectations of customers, who not only want to buy, but also to experience the corresponding emotions during the shopping process. Likelihood of success can be significantly increased by comprehensive and methodical measures within the area considered according to the approach proposed in this article. Customers' trust in a provider depends heavily on the emotional satisfaction experienced as a result of each interaction with its brand. Hence, in order to strengthen loyalty, it is essential to satisfy both the rational and emotional needs of stakeholders in all interactions with the commercial offer. Delivering value to stakeholders while maintaining sustainable business growth is one of the key challenges for today's entrepreneurs. A fundamental question being asked by marketers is how effective management of people's experiences under a brand emblem translates into a company's economic performance, particularly in a highly competitive environment.

Based on the literature studies conducted and own research, it is reasonable to state that given the current market conditions, a proper online merchandising strategy seems to depend on the ability to create an engaging and exciting buyer experience that increases brand trust, loyalty and earnings of the online shop owner.

Effective online merchandising shall respect the fact that experience is an internal and subjective response to a direct or indirect interaction occurring between a brand (or related business) and a stakeholder, throughout the duration of their interaction and leading to engagement on rational, emotional, sensory, physical and spiritual levels.

Considering the fact that today's consumers are eager to use e-commerce, it is worth dosing marketing stimuli aimed at the awareness and subconscious of stakeholders that create value, influence behaviour, encourage the creation of relevant experiences and contribute to a closer human-brand relationship, which is arguably what methodical online merchandising activities are all about.

The author understands the limited nature of the qualitative research carried out and therefore intends to pursue it on other sites and plans to expand it to examine the reactions and reception and evaluation of such online merchandising activities by the stakeholders involved.

As a conclusion, the literature studies and empirical research carried out consolidated the view that marketers managing online shops should rethink the following issues: Are appropriate employee, customer, partner, media, web, community and other experiences being built by means of marketing programmes? Does the brand of the online shop succeed in fulfilling its promise? Does the process of offering value under a specific brand emblem sufficiently match expectations and trends, taking into account the actions of major competitors, create a positive online shop brand experience for the recipients? Does the online shop's branding distinguish it from its competitors? Is customer loyalty to the online shop being built appropriately among the targeted customers? To what extent are online merchandising tools conducive to the creation of relevant customer experiences adapted to the current circumstances and are characterised by creativity and relevance to them? Finally, are they taking advantage of the opportunities arising from socio-scientific and technical progress, including the development of the Internet, or marketing activities in general?

When applied well, online merchandising activities: are in line with trends in the behaviour and expectations of customers and other stakeholders; contribute to the rationalisation of expenditure; generate multiple benefits (reliable information, building relationships, providing information and entertainment, opportunity for key stakeholders to participate in the provider's activities, creation of a brand community, value creation, effective differentiation from competitors...).

To identify recommendations for marketers interested in implementing effective online merchandising activities, the following points should be noted: 1) Alignment of all supporting marketing activities with the expectations of today's consumers and other stakeholders (media representatives, Internet users, potential social and/or business partners.) 2) Skilful 'crowd

engagement' as today's stakeholders and especially Internet users demonstrate strong tendencies towards prosumer behaviour. 3) Activities should be based on the results of research on, for example, what the key target groups are interested in, what is important to them and what can be combined with the online shop's offer and activities. 4) A holistic approach to the human being, i.e. influencing the individual on mental, physical and spiritual levels, is essential. 5) Methodical actions require an adequate budget, hiring of professionals, allocating enough time and launching the entire spectrum of activities listed in this article. 6) Flexibility and responsiveness are vital success factors. 7) Skilful positioning and building an appropriate and unique online shop brand tailored to the profile of the customer handled is also important.

Marketers managing online shops need to take steps whereby they participate, so to speak, in the life of their communities. Making references to current events, generating content and allowing for participation are particularly important. Consistency, multimediality, creativity and a methodical approach is what counts.

To sum up, in the light of the considerations and research carried out, it seems reasonable to conclude that online merchandising activities should be considered methodical and valuable and worth following. Moreover, they generate multifaceted benefits for all market players (brand stakeholders, representatives of the brand's real and virtual communities and other collaborators and affiliates) in line with social, technical, technological, market and management considerations, including the pursuit of a balanced approach in every aspect of the activities of the brand owner under which the online shop operates.

Given the current market conditions (intense competition, digitalisation, information society, technical and technological advances, development of research into buyer behaviour – neuroresearch, improvement of marketing tools, methods and procedures...), effective online merchandising constitutes a complex of activities addressing the mind, soul and body of the recipient, who responds simultaneously on every level: mental, physical and spiritual.

Technical and technological advances and the development of the Internet are significantly influencing the behaviour of buyers, especially purchasing behaviour. A digital consumer equipped with mobile devices has basically permanent access to the web. Such a consumer has the ability to use multiple shopping channels simultaneously according to the situation and circumstances. He also has more and more opportunities as a result of the popularisation of various applications. Concluding, important determinants of successful online merchandising activities are innovation combined with creativity, flexibility, adaptation of supporting measures in line with technical and technological advances.

References

1. Bailey, S., Baker, J. (2022). *Visual merchandisingu for fashion.* London: Bloomsbury Publishing.
2. Berkhout, C. (2019). *Assortment and merchandising strategy. Building a retail plan to improve shopper experience*. USA: Palgrave Macmillan.
3. Binsztok, A., Zuzański T. (2013). *Jak oczarować klientów w sklepie, czyli merchandising* zelementami *psychologii zachowań konsumenckich*. Gliwice: Helion.
4. Borusiak, B. (2009). *Merchandising*. Poznań: Wydawnictwo Akademii Ekonomicznej w Poznaniu.
5. Borusiak, B., Wanat, T. (2020). *Merchandising w handlu stacjonarnym i internetowym.* Poznań: Wydawnictwo Uniwersytetu Ekonomicznego w Poznaniu.
6. Brzustewicz, P. (2023). Incorporating sustainable marketing in the new product development process: evidence from companies operating in Poland. *Qeios*, pp. 1-13, doi:10.32388/51voi0.
7. Campbell, A. (2020). *Agile: Essentials of Team and Project Management.* Manifesto for Agile Software Development. London: Wiley.
8. Chaffey, D., Smith, P.R. (2017), *Digital marketing excellence: planning, optimizing and integrating online marketing*. New York: Routledge.
9. Chojan, A. (2023). Założenia polityki Unii Europejskiej wobec zrównoważonego rozwoju. In: E. Florczak (Ed.), *Zrównoważony rozwój jako trend kształtujący współczesną gospodarkę* (pp. 3-12). Warszawa: C.H. Beck.
10. Clatworthy, S. (2022). *Doświadczenia klientów: od idei firmy do zachwytu konsumenta*. Warszawa: ICAN Institute.
11. Cox, R., Brittain, P. (2000). *Zarządzanie sprzedażą detaliczną*. Warszawa: PWE.
12. Cyrański, R. (2024). *E-commerce merchandising trends: Jakie są najnowsze trendy?* Retrieved from: https://funkymedia.pl/nowe/ecommerce-merchandising-trends-jakie-sa-najnowsze-trendy#jak-wykorzystac-nowe-trendy-w-ecommerce-merchandisingu-do-zwiekszenia-sprzedazy, 4.07.2024.
13. *Czym jest merchandising w e-commerce i na czym polega praca na stanowisku merchandisera?* (2024). Retrieved from: https://digitalx.pl/czym-jest-merchandising-w-e-commerce-i-na-czym-polega-praca-na-stanowisku-merchandisera/, 10.07.2024.
14. Diamond, J., Diamond, E. (2007). *Merchandising: magnetyzm przestrzeni handlowej.* Gliwice: Helion.
15. Dudka, B. (2024). *Badania przestrzeni sklepu – Kiedy warto w nie inwestować?* Retrieved from: http://www.branchbrothers.pl/blog/badania-przestrzeni-sklepu-kiedy-w-nie-inwestowac, 7.07.2024.

16. Ebster, C., Garaus, M. (2011). *Store design and visual merchandising. Creating store space that encourages buying*. New York: Business Expert Press.
17. *E-commerce w Polsce 2024: Najnowsze trendy i wskaźniki –Raport Izby Gospodarki Elektronicznej* (2024). Retrieved from: https://ecommercenews.pl/e-commerce-w-polsce-2024-najnowsze-trendy-i-wskazniki-raport-izby-gospodarki-elektronicznej/, 18.07.2024.
18. Egorova, A.A., Grishunin, S.V., Karminsky, A.M. (2022). The Impact of ESG factors on the performance of Information Technology Companies. *Procedia Computer Science, No. 199*, pp. 339-345.
19. Feldy, M. (2012). *Sklepy internetowe. Jak złapać w sieci e-konsumentki i e-konsumentów*. Warszawa: Oficyna a Walters Kluwer business.
20. Florczak, E. (Ed.) (2023). *Zrównoważony rozwój jako trend kształtujący współczesną gospodarkę.* Warszawa: CH Beck.
21. Foroudi, P., Palazzo, M. (2021). *Sustainable Branding: Ethical, Social and Environmental Cases and Perspectives*. New York: Routledge.
22. Foster, M. (2024). *E-commerce personalization trends report 2024. 7 ecommerce personalization trends and strategies to win in 2024.* SledeFill.
23. Foxall, G.R., Goldsmith, R.E. (1998). *Psychologia konsumenta dla menadżera marketingu*. Warszawa: PWN.
24. Gajewski, S. (1997). *Zachowanie się konsumenta a współczesny marketing*. Łódź: Wydawnictwo Uniwersytetu Łódzkiego.
25. Garrido-Morgado, A., Gonzalez-Benito, O. (2015). Merchandising at the point of sale: differential effect of end of aisle and islands. *Business Research Quarterly, Vol. 18*, pp. 57-67, doi: https://doi.org/10.1016/j.brq.2013.11.004.
26. Ghaffar, A., Zaidi, S.S.Z., Islam, T. (2023), An investigation of sustainable consumption behavior: the influence of environmental concern and trust in sustainable producers on consumer xenocentrism. *Management of Environmental Quality: An International Journal, 34(3)*, pp. 1-23, doi: 10.1108/MEQ-05-2022-0153.
27. Hansen, H. (2021). *Brand Management in a Co-Creation Perspective: Communication as Constitutive of Brands*. New York: Routledge.
28. Ind, N., Horlings, S. (2016), *Brands with a conscience: how to build a successful and responsible brand*. New York: Kogan Page Publishers.
29. *Jak korzystamy z urządzeń mobilnych w procesie sprzedaży?* (2024). Retrieved from: http://nf.pl/manager/jak-korzystamy-z-urzadzen-mobilnych-w-procesie-sprzedazy,47720,1, 17.07.2024.
30. Kamiński, R. (2022). *Zrównoważony rozwój przedsiębiorstw jako przedmiot raportowania niefinansowego*. Warszawa: PWE.
31. Kapelczak, K. (2024). *Sekret sukcesu e-commerce: Jak personalizacja zwiększa zyski i zadowolenie klientów?* Retrieved from: https://widoczni.com/blog/personalizacja-w-ecommerce/, 10.07.2024.

32. Keller, K.L. (2013). *Strategic brand management. Building, measuring and managing brand equity*. New York: Pearson Education Limited.
33. Kocot, M., Maciaszczyk, M. (2024). Agile customer service practices in the e-commerce development process. *Scientific Papers of Silesian University of Technology, Organization and Management Series, No. 196,* pp. 209-223, doi: 10.29119/1641-3466.2024.196.14.
34. Kocot, M., Maciaszczyk, M. (2024). Agile practices in activating customers to co-create the offer. *Scientific Papers of Silesian University of Technology, Organization and Management Series, No. 197,* pp. 350-364, doi: 10.29119/1641-3466.2024.197.20.
35. Kotarbiński, J. (2021). *Marka 5.0. Człowiek i technologie: jak tworzą nowe wartości?* Warszawa: PWN.
36. Kotler, Ph., Kartajaya, H., Setiawan, I. (2021). *Marketing 5.0. Technology for humanity.* Hoboken: Wiley.
37. Larsen, F. (2023). *Sustainable energy branding: Helping to save the planet*. London: Routledge.
38. Levy, J. (2021). *UX strategy. Product strategy technics for devising innovative digital solutions*. USA: O'Reilly Media, Inc.
39. Levy, M., Weitz, B. (2004). *Retailing management*. New York: McGraw-Hill Irwin.
40. Lubin, L. (2022). *How to build your brand: implementing a proven and effective process*. Toronto: Wiley.
41. Martinez-Lopez, F.L., Martinez, L.F., Brüggemann, P. (2024). *Advanced in digital marketing and ecommerce. Fifth International Conference 2024*. Switzerland: Springer International Publishing AG.
42. Morgan, T. (2008). *Merchandising. Projektowanie przestrzeni sklepu*. Warszawa: Arkady.
43. Morgan, T. (2022). *Visual merchandisingu. Window displays, in-store experience.* London: Quercus Publishing.
44. *Polski rynek e-commerce w latach 2024-2028* (2024). Retrieved from: https://www.trade.gov.pl/wiedza/polski-rynek-e-commerce-w-latach-2024-2028/, 5.09.2024.
45. *Raport e-commerce* (2021). Retrieved from: https://gemius.com/pl/news/raport-e-commerce-w-polsce-2021/, 10.07.2024.
46. Russel, P.J. (2015). *Field visual merchandising strategy: developing a national in-store strategy using a merchandising service organization*. Philadelphia: Kogan Page Limited.
47. Schmitt, B.H. (2011). *Experience marketing: concepts, frameworks and consumer insights*. Boston/Delft: NOW The essence of knowledge.
48. *Sklepy internetowe dla wymagających użytkowników* (2024). Retrieved from: http://www.aptusshop.pl/sklepy_internetowe/merchandising-w-sklepie-internetowym.php, 12.07.2024.
49. *Sklepy przyszłości. Raport* (2018). Retrieved from: Interia.com, 11.07.2024.

50. Skowronek, I. (2014). *Zmysły dla zysku. Marketing sensoryczny w praktyce*. Warszawa: Poltext.
51. Smilansky, S. (2009). *Experiential marketing. A practical guide to interactive brand experiences*. London/Philadelphia: Kogan Page Limited.
52. Tarczydło, B. (2005). Merchandising jako nowoczesna metoda w zarządzaniu sprzedażą detaliczną. In: J. Skalik (Ed.), *Zmiana warunkiem sukcesu: przeobrażenia metod i praktyk zarządzania. Prace Naukowe Akademii Ekonomicznej we Wrocławiu, no. 1092* (pp. 369-377).
53. Tarczydło, B. (2014). Wzbudzanie emocji i kreowanie doświadczeń w kampanii komunikacji marketingowej. *Marketing i Rynek, No. 4,* pp. 159-165.
54. Tarczydło, B. (2015). Kierunki rozwoju działań merchandisingowych w drugiej dekadzie XXI wieku. *Zeszyty Naukowe Uniwersytetu Szczecińskiego – Problemy Zarządzania, Finansów i Marketingu, nr 866. Marketing przyszłości: trendy, strategie, instrumenty: komunikacja marketingowa przedsiębiorstwa z otoczeniem, nr 39*, pp. 97-105, doi:10.18276/pzfm.2015.39-08.
55. Tarczydło, B. (2016). Paradygmat marki w dobie digitalizacji i technologii mobilnej, *Handel Wewnętrzny, Vol. 62, No. 5*, pp. 314-323.
56. Tarczydło, B., Miłoń, J. (2019). Kreowanie doświadczeń interesariuszy powiązanych z marką. Wyniki badań. In: N. Iwaszczuk (Ed.), *Innowacyjność w działalności gospodarczej* (pp. 135-151). Kraków: IGSMiE PAN.
57. Tarczydło, B., Miłoń, J., Klimczak, J. (2023). Experience branding in theory and practice. Case study. *Scientific Papers of Silesian University of Technology Organization and Management Series*, *No. 178*, pp. 617-636, doi: 10.29119/1641-3466.2023.178.33.
58. Targiel, K.S. (2022). Project Success and Communication with Stakeholders. *Scientific Paper of Silesian University of Technology, Organization and Management Series, Vol. 155, No. 34,* pp. 527-534, doi: 10.29119/1641-3466.2022.155.34.
59. Tobała, K. (2024). *Co to jest i na czym polega e-merchandising w sklepie internetowym?* Retrieved from: https://blog.sky-shop.pl/e-merchandising-prezentacja-produktow-w-sklepie-internetowym/, 10.07.2024.
60. Tracy, B. (2023). *Psychologia sprzedaży. Podnieś sprzedaż szybciej i łatwiej, niż kiedykolwiek uznawałeś za możliwe*. Warszawa: MT Biznes.
61. *Trendy w visual merchandising* (2024). Retrieved from: http://fashionbusiness.pl/trendy-w-visual-merchandisingu/, 10.07.2024.
62. Troian, V. (2023). Marketing cyfrowy jako narzędzie promocji zrównoważonego rozwoju dla konsumentów oraz biznesu w Internecie. In: J. Buzek, H.A. Kretek, M. Staniszewski (Eds.), *Zrównoważony rozwój i europejski zielony ład imperatywami doskonalenia warsztatu naukowca* (pp. 373-384). Gliwice: Wydawnictwo Politechniki Śląskiej.
63. Underhill, P. (2001). *Dlaczego kupujemy?* Warszawa: MT Biznes.

64. United Nations (2015). *The 2030 Agenda for Sustainable Development – The 17 Goals*. Retrieved from: https://sdgs.un.org/goals, 13 January 2024.
65. Wan, L.C., Poon, P.S., Yu, C. (2016). Consumer reactions to corporate social responsibility brands: the role of face concern. *Journal of Consumer Marketing, Vol. 33, No. 1*, pp. 52-60. ISSN: 0736-3761, doi: 10.1108/JCM-03-2013-0493.
66. Wilk, I. (2014). Komunikacja z rynkiem docelowym w ramach marketing zrównoważonego. *Zeszyty Naukowe Uniwersytetu Szczecińskiego. Problemy Zarządzania, Finansów i Marketingu*, *No. 35*, pp. 199-207. Retrieved from: http://yadda.icm.edu.pl/yadda/element/bwmeta1.element.ekon-element-000171310403.
67. Wilk, I. (2015). Konsument zrównoważony jako segment odniesienia dla działań marketingowych przedsiębiorstwa. *Zeszyty Naukowe Uniwersytetu Szczecińskiego. Problemy Zarządzania, Finansów i Marketingu*, *No. 38*, pp. 183-191, doi: 10.18276/pzfm.2015.38-17.
68. Williams, A., Mullin, R. (2011). *Field marketing. Skuteczne zastosowania marketingu terenowego*. Warszawa: Oficyna Wydawnicza Wolters Kluwer Polska.
69. Witek, L. (2007). *Merchandising w małych i dużych firmach handlowych*. Warszawa: C.H. Beck.
70. Wojciechowska, K. (2020). *Customer Experience Management. Moc pozytywnych doświadczeń na ścieżce twojego klienta*. Gliwice: One press Helion.
71. Wolniak, R. (2023). Design thinking and its use to boast innovativeness. *Scientific Papers of Silesian University of Technology, Organization and Management Series, No. 170,* pp. 647-662, doi: 10.29119/1641-3466.2023.170.39.
72. Wolniak, R. (2024). Analyzing customer behaviour – employing business analytics within industry 4.0 ecosystems. *Scientific Papers of Silesian University of Technology, Organization and Management Series, No. 195,* pp. 631-646, doi: 10.29119/1641-3466.2024.195.39.
73. Wolniak, R., Gajdzik, B., Grebski, W. (2023). Environmental sustainability in business. *Scientific Papers of Silesian University of Technology Organization and Management Series, No. 175*, pp. 611-630, doi: 10.29119/1641-3466.2023.175.39.
74. Wolniak, R., Grebski, W. (2023). Comparision of traditional and sustainable business practices. *Scientific Papers of Silesian University of Technology Organization and Management Series, No. 177*, pp. 671-688, doi: 10.29119/1641-3466.2023.177.39.
75. Wrzesińska-Kowal, J. (2024). The evolution of retail trade in Poland following economic transformation. *Scientific Papers of Silesian University of Technology, Organization and Management Series, No. 201,* pp. 391-403, doi: 10.29119/1641-3466.2024.201.30.
76. Wu, J., Kim, A.J., Koo, J. (2015). Co-design visual merchandising in 3D virtual stores: a facet theory approach. *International Journal of Retail & Distribution Management, Vol. 43, Iss. 6*, pp. 538-560.
77. Zaltman, G. (2003). *Jak myślą klienci? Podróż w głąb umysłu rynku*. Poznań: Forum.

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ORGANIZATION AND MANAGEMENT SERIES NO. 213

BUSINESS GREEN INITIATIVES AND ENVIRONMENTAL OUTCOMES: AN EMPIRICAL ANALYSIS

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Purpose: The article addresses the current and important research area of business sustainability, which is attracting the interest of both theoreticians and management practitioners. It focuses on the environmental dimension of business sustainability. The main objective of the article is to identify the relationship between activities in the environmental dimension and sustainable environmental outcomes.
Design/methodology/approach: The study covers organizations 303 operating in Poland and is based on a questionnaire. The collected data was used to build a regression model.
Findings: The results revealed statistically significant relationships between environmental outcomes and variables: value proposition, transport & distribution and suppliers & subcontractors.
Research limitations/implications: The variables were measured using subjective indicators. In addition, the research was conducted only in companies operating in Poland and the results may be typical of businesses operating in this country. Therefore, the research should be extended to other countries, and it would be particularly interesting to compare with companies operating in countries where sustainability-related indicators are highly rated. It would also be very interesting to expand the data gained through questionnaires through interviews and case studies.
Originality/value: Linking green-focused business activities to the benefits that businesses can achieve in the area of environmental outcomes as a result.
Keywords: management, sustainability, triple bottom line, environmental dimension, environmental outcomes.
Category of the paper: research paper.

1. Introduction

In the context of changes in the business environment and the growing awareness of customers, the pressure to engage in sustainable practices is increasing significantly. Thus, it is the indicators in the three basic areas of economic, social and environmental that are becoming key to ensuring competitive advantage. At the same time, in recent years,

the increasing importance of environmental concerns in the eyes of customers worldwide, their preferences for choosing eco-friendly products, and their positive attitude toward environmentally conscious companies indicate the growing significance of environmental sustainability for businesses (Eminova, 2023). This means that businesses should focus their activities more on protecting and conserving natural resources and reducing the negative impact of human activities on the environment. The actions that businesses take must also be taken from a broader perspective, not only of the businesses themselves, but of the supply chains, in cooperation with stakeholders, such as customers, suppliers, partners and sometimes competitors. However, currently, the sustainable development paradigm is complemented by the idea of a "green economy" (Mamedova, 2022). The article examines the relationship between businesses' environmental sustainability activities and their environmental outcomes.

2. Concept of sustainable development

The concept of sustainable development is based on the assumption that meeting the needs of modern societies will take place without compromising the ability to meet the needs of future generations. This means expanding the view of the results achieved from a focus on the economic to a social and environmental dimension. The concept grew out of the need to take care of people's long-term needs, because environmental management developed without meeting the requirement for constant renewal of life-sustaining resources, which inevitably leads to their depletion, the degradation of ecosystems. Sustainability at the business level means maintaining a balance between these three areas, leading to long-term stability and prosperity. In the economic area, it means that organizational resources are used efficiently taking into account the needs of diverse stakeholders ensuring sustainable economic growth. In the social area, sustainable development refers to ensuring equality, security, protection of human rights, social justice and improving the quality of life for all (the Sustainable Development Goals emphasize the need to eliminate poverty and inequality). In the environmental area, sustainable development focuses on the management of natural resources, emphasizing the need to protect non-renewable resources and ecosystems. So, on the one hand, business activities should focus on reducing the negative impact of people on the environment (minimizing footprints) and maximizing the positive one (e.g., taking care of biodiversity). Strategic decisions of businesses should aim to integrate the three perspectives. Economic action coupled with care for the environment and social responsibility means compliance with the concept of sustainable development. This requires the implementation of new solutions that will promote the reduction of energy consumption, water consumption, or the reduction of environmental pollution and the extension of the life cycle of closed-loop products.

3. The Triple Bottom Line – Planet

Business sustainability has developed into a strategic management approach that integrates economic, social, and environmental goals (Brandon-Jones, 2015). This evolution emphasizes responsible practices, innovation, resource efficiency, and stakeholder engagement, which enhance an organization's reputation and value through corporate social responsibility. Elkington introduced the concept of evaluating a business model from three sustainability perspectives, leading to the "Triple Bottom Line" (TBL) model. The TBL framework, proposed by Elkington in 1994, includes three essential indicators: Profit, Planet, and People, offering a holistic method for assessing an organization's impact across economic, environmental, and social dimensions (Figure 1).

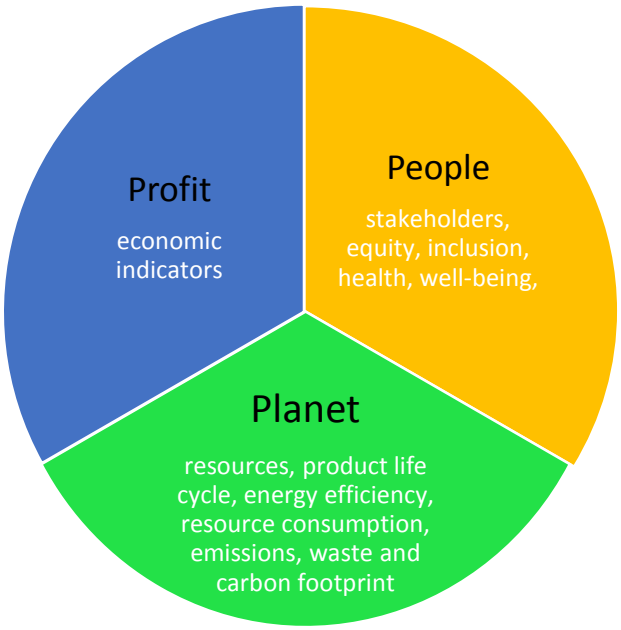

Figure 1. Triple bottom line layers.

Source: author's own work based on Elkington TBL concept.

By incorporating Elkington's Triple Bottom Line indicators, businesses can make decisions beyond immediate profits, considering the long-term impact on profit, the planet and people. The framework emphasizes the interconnectedness of economic success, environmental responsibility and social well-being (Thiago et al., 2021; Brandon-Jones, 2015). Organizations that adopt this approach are, in essence, better equipped to create value for a broader set of stakeholders, including communities and the environment, not just shareholders. Elkington's innovative model challenges traditional business practices, encouraging a shift toward increasing sustainability and corporate responsibility. As global challenges increase, the Triple Bottom Line functions as a guiding framework, leading organizations toward a more responsible and sustainable way of operating. As a development of Elington's concept, Joyce and Paquin (2016) proposed a tool for designing sustainable business models by adding two

additional layers to the classic Business Model Canvas: an environmental layer based on a life cycle perspective and a social layer incorporating a stakeholder perspective. The authors emphasized the growing pressure on organizations to actively respond to the challenges associated with implementing sustainable values.

Elkington's environmental indicator in the TBL framework focuses on the "Planet" and assesses an organization's impact on environment. Midgley and Arya (2022) described the TLBMC (Tool Triple Layer Business Model Canvas) which was used to expand concept sustainable business. Moreover the environmental dimension is the most important, social and economic are secondary, because everything depends on resources (Porrit, 2007; Bansal, 2005; Correira, 2019). The earth dimension is concentrate on product life cycle, energy efficiency, resource consumption, emissions, waste and carbon footprint (Meera, 2016). The environmental dimension is crucial to sustainable development. Effective management of environmental impact not only leads to the protection of the planet in the long term, but also results directly into an increase in competitive advantage, building a positive reputation. Elkington's Triple Bottom Line framework includes issues that collectively assess an organization's environmental impact: natural resource management and emissions and pollution reduction (Elkington, 1994). Slaper et al. (2011) give examples of indicators in this area: sulfur dioxide concentrations, nitrogen oxide concentrations, selected priority pollutants, excess nutrients, electricity consumption, fossil fuel consumption, solid waste management, hazardous waste management, land use/land cover change. Importantly, to ensure the widest possible range of positive impacts, environmental indicators should also include supply chain activities.

4. Environmental initiatives and environmental outcomes

The growing awareness of sustainability is leading to a search for factors that influence sustainable performance also broken down into three basic areas: economic, social and environmental. The subject of many scientific studies is the relationship between the environmental activities of businesses and their sustainable environmental performance (i.e. Gimenez et al., 2012; Albertini, 2013; Madsen, Ulhøi, 2016; Latan et al., 2018; Trumpp et al., 2017; Wagner, 2015; Solovida et al., 2021; Petrović-Ranđelović et al., 2023; Walecka-Jankowska et al., 2023a, 2023b). This research considers how different environmental strategies and practices affect the environmental performance of businesses. Gimenez et al. (2021) point out that organizations strive for sustainable use of organizational resources by applying internal environmental programs, thus minimizing resource consumption and at the same time negative environmental impact. Also within the supply chain, which is key to achieving sustainable performance (not just in the environmental area) (Gimenez et al., 2012). Businesses are also

monitoring the life cycle of products, so they can make changes that not only address the production and distribution phase, but also the use phase. In addition, businesses are increasingly seeking environmental certifications (e.g., ISO 14001) that focus on reducing, for example, emissions and other pollutants (Hörisch et al., 2015; Solovida et al., 2021). What positively influences the achievement of environmental performance (So et al., 2017). Gotschol et al., (2014) point to the positive impact of environmental management on environmental performance, emphasizing that the impact is greater if businesses reinvest profits from environmental activities in further initiatives in this area. Other studies indicate a link between emission reductions and environmental performance, despite the fact that this involves increased costs (Dangelico, Pontrandolfo, 2015; Robaina et al., 2020). Walecka-Jankowska et al. (2023a, 2023b) indicate a link between the implementation of environmental innovations and environmental performance. Research described by Juma et al. (2021) analyzes the positive impact of supply chain management on environmental performance. Moreover, the research indicates a positive relationship between environmental performance and business economic value creation (Petrović-Ranđelović et al., 2023). Thus, as the cited studies indicate, there is a positive correlation between the pro-environmental activities of businesses and their environmental performance. The implementation of pro-environmental measures can significantly improve sustainable performance contributing to greater sustainability of the business in the long term, but also, as Roy et al. (2021) indicate, to a higher evaluation of the business by investors.

5. Research methodology

The primary aim of the paper is to investigate the relationship between organizational activities in environmental dimension and environmental outcomes. The broader study, an excerpt of which is included in the article, examined results along three dimensions: economic, environmental and social. Measurement of environmental outcomes included among others: environmental value proposition, customer participation in various phases of the process, product utilization distribution, environmental benefits, key resources and activities, and environmental impact.

In order to verify the relationships, a survey was conducted, for which the author's questionnaire was used (5-point Likert Scale was adapted). The study was conducted using a questionnaire that was intended to be appropriate for any organization regardless of size, activity profile, or affiliation to a branch of the economy. Employees with a broad view of the organizations surveyed (each respondent represented a different organization) were asked to complete the survey. The survey was conducted at the end of 2022, targeting companies operating in Poland, and resulted in 303 correct responses. The respondent profiles are: presented in Table 1.

Table 1.
Respondents by size of organization surveyed

Enterprise size (number of employees)	
Micro (less than 10)	133
Small enterprises (10-49)	83
Medium (50-249)	60
Large (over 250)	27

Source: authors' own work.

In order to examine the relation between activities in environmental dimension (Joyce, Paquin, 2016) and environmental outcomes (Zgrzywa-Ziemak, 2019), the following key variables were defined (Figure 2). The reliability measured by Cronbach's alpha coefficient of all variables was higher than 0.88, which means a high level of reliability of measurement scales (information about the number of items forming each variable is provided at the top of each variable).

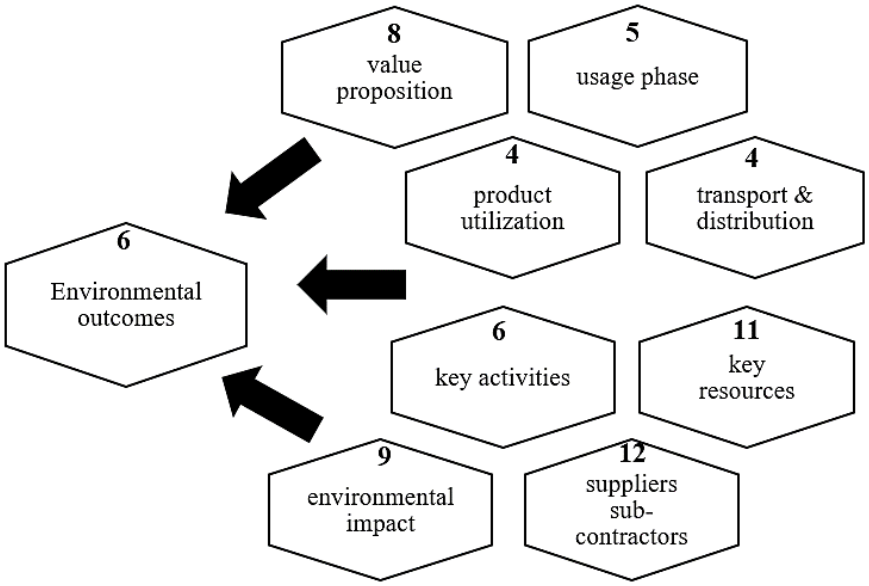

Figure 2. Variables.

Source: author's own work.

Variables forming the environmental dimension:

- Usage phase – Evaluates the extent to which the business involves customers in product design and whether the products/services offered support customers in saving resources (water, energy), repairability and extended use, and implements the concept of product sharing.
- Value proposition – assesses the extent to which the business contributes to safety, sustainable use of resources (renewable and non-renewable), development of technologies that reduce environmental risks, reduction of energy intensity and waste production, raising environmental awareness, and generating revenue from waste processing.

- Transport & distribution - assesses the extent to which the business takes environmental aspects into account in various areas of the business, such as business travel, transportation of goods to customers, distribution of goods, and use of packaging.
- Product utilization - assesses the extent to which the business implements product disposal measures, such as full recyclability, biodegradability, life extension through parts replacement and the use of reusable packaging.
- Key resources - assesses the extent to which key resources used by the business, such as agricultural crops, animal husbandry, natural resources, rare earth metals, the environment, infrastructure, and various chemicals and pharmaceuticals, affect the environment, including the carbon footprint.
- Key activities - assesses the extent to which key business activities, such as internal and external logistics, production processes, marketing and sales, after-sales service and support activities, affect the environment.
- Suppliers and subcontractors - assesses which aspects are important for the business when working with suppliers and subcontractors, such as the ability to recycle and repair components, generate by-products, extend product life cycle, industrial symbiosis, participate in the green supply chain, and shorten the supply chain.
- Environmental impact - assesses the extent to which the business affects the environment in terms of CO2 and other greenhouse gas emissions, production of biodegradable and non-biodegradable waste, production of industrial and other wastewater, and use of natural resources (renewable and non-renewable) and water consumption.

To verify the hypotheses describing the relationship between activities in environmental dimension and environmental outcomes, statistical analyzes were carried out. First, a correlation analysis was conducted using Pearson's coefficient (all correlations are significant at the 0.01 level – bilateral) - presented in Table 2.

Table 2.
Pearson's correlation

	Environmental outcomes	**Usage phase**	**Value proposition**	**Transport & distribution**	**Product utilization**	**Key resources**	**Key activities**	**Suppliers and subcontractors**	**Environmental impact**
Pearson's correlation	1	0,401**	0,488**	0,482**	0,220**	0,227**	0,249**	0,284**	0,193**
Relevance (bilateral)		0,001	0,001	0,001	0,001	0,001	0,001	0,001	0,001
N	303	303	303	303	303	303	303	303	303

Source: authors' own work.

The correlation analysis shows significant relations between all activities in environmental dimension and environmental outcomes. It should be noted that the is at a rather similar level and oscillates between 0.193 and 0.488, the highest correlation (0,49 and 0,482) is between environmental outcomes and two variables: value proposition and product distribution.

Since the analysis of pairwise correlations revealed strong associations, it was decided to perform stepwise regressions and model was obtained: F (8,294) = 14,981; p < 0,001.

This model seem to fit the data well and the regression equations can be written as follows:

$$Y = b_0 + b_1 \times X_1 + b_2 \times X_2 + b_3 \times X_3 + b_4 \times X_4 + b_5 \times X_5 + b_6 \times X_6 + b_7 \times X_7 + b_8 \times X_8$$

where:

Y – environmental outcomes,

X_1 – Usage phase,

X_2 – Value proposition,

X_3 – Tr ansport & distribution,

X_4 – Product utilization,

X_5 – Environmental benefits,

X_6 – Key resources,

X_7 – Key activities,

X_8 – Suppliers and subcontractors,

X_9 – Environmental impact.

$$\textbf{Environmental Outcomes} = 2{,}202 + 0{,}139 \times X_2 + 0{,}127 \times X_3 + 0{,}030 \times X_7$$

where:

X_2 – Value proposition,

X_3 – Transport & distribution,

X_7 – Suppliers and subcontractors.

Analysis of the collected data revealed statistically significant relationships between environmental performance and the value proposition, transport & distribution, and cooperation with suppliers and subcontractors (presented in Figure 3).

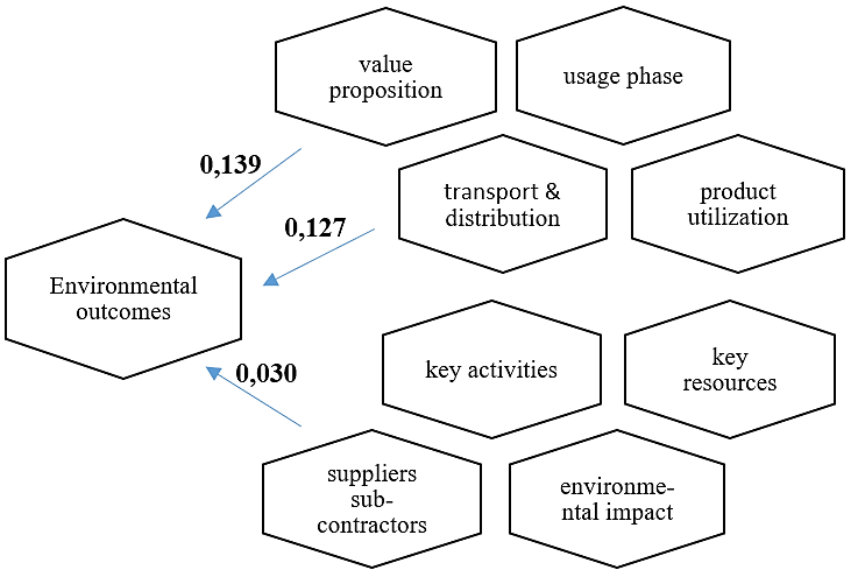

Figure 3. Relationship between results and environmental variables.

Source: author's own work.

6. Conclusions

Analysis of the statistical results obtained indicates that the following factors are most strongly related to environmental performance: value proposition, transportation & distribution, and suppliers & contractors. An increase in the value of these variables mean that the environmental performance of businesses is higher. This means that organizations should focus their efforts on making sustainability a differentiator in the products/services they offer. A manifestation of this could be a focus on improving safety, use of renewable and non-renewable resources, on technologies that reduce environmental risks, reduce energy intensity and waste production, but also on raising environmental awareness among employees, customers, partners. What's more, integrating environmental sustainability should also address environmental aspects in different areas of operations - deliveries, transportation to the customer, business travel and how they are packaged. Higher environmental outcomes require cooperation throughout the supply chain - assessing the recyclability and reparability of supplied components, generating by-products, extending product life cycles, shortening the chain and taking care of environmental indicators. Thus, organizations should focus on these very elements if they want to improve their sustainable environmental outcomes.

There are several limitations that should be taken into account when interpreting the results. The variables were studied using subjective assessment. In addition, the research was conducted in businesses operating in Poland and the results may be typical of businesses operating in this country. Thus, the research should be extended to other countries, especially interpreting seems a comparison to businesses operating in countries where indicators related to sustainability are rated highly. It would also be very interesting to expand the data gained through questionnaires through interviews and case studies.

References

1. Albertini, E. (2013). Does environmental management improve financial performance? A meta-analytical review. *Organization and Environment*, *26(4)*, pp. 431-457.
2. Bansal, P. (2005). Evolving sustainably: A longitudinal study of corporate sustainable development. *Strategic Management Journal*, *26(3)*, pp. 197-218.
3. Brandon- Jones, E. (2015). Triple- bottom line. *Wiley Encyclopedia of Management*, *1-1*.
4. Correia, M.S. (2019*)*. Sustainability: An overview of the triple bottom line and sustainability implementation. *International Journal of Strategic Engineering (IJoSE), 2(1)*, pp. 29-38.

5. Dangelico, R.M., Pontrandolfo, P. (2015). Being 'green and competitive': The impact of environmental actions and collaborations on firm performance. *Business Strategy and the Environment*, *24(6)*, pp. 413-430.
6. Eminova, A. (2023). Environmental sustainability as a competitive advantage of enterprise in the global market. *Labor and social relations*.
7. Gimenez, C., Sierra, V., Rodon, J. (2012). Sustainable operations: Their impact on the triple bottom line. *International Journal of Production Economics*, *140*, pp. 149-159.
8. Gotschol, A., De Giovanni, P., Vinzi, V.E. (2014*).* Is environmental management an economically sustainable business? *Journal of Environmental Management, 144*, pp. 73-82.
9. Hörisch, J., Ortas, E., Schaltegger, S., Álvarez, I. (2015). Environmental effects of sustainability management tools: An empirical analysis of large companies. *Ecological Economics*, *120*, pp. 241-249.
10. Joyce, A., Paquin, R.L. (2016). The triple layered business model canvas: A tool to design more sustainable business models. *Journal of Cleaner Production*, *135*.
11. Juma, L., Zimon, D., Ikram, M. (2021). A relationship between supply chain practices, environmental sustainability and financial performance: Evidence from manufacturing companies in Jordan. *Sustainability*, *13(4)*, *2152*.
12. Latan, H., Chiappetta Jabbour, C.J., Lopez de Sousa Jabbour, A.B., Renwick, D.W.S., Wamba, S.F., Shahbaz, M. (2018). 'Too-much-of-a-good-thing'? The role of advanced eco-learning and contingency factors on the relationship between corporate environmental and financial performance. *Journal of Environmental Management*, *220*, pp. 163-172.
13. Madsen, H., Ulhøi, J.P. (2016). Corporate environmental initiatives in small and medium sized enterprises and their outcomes: A longitudinal study. *Business Strategy and the Environment*, *25(2)*, pp. 92-101.
14. Mamedova, N.M., Bezveselnaya, Z.V., Ivleva, M.I., Komarova, V. (2022). Environmental management for sustainable business development. *Entrepreneurship and Sustainability Issues*, *9(3),* 134.
15. Meera, S., Tabrez, A. (2016). Triple bottom line approach to environmental protection. *Social Science Research Network*.
16. Petrović-Ranđelović, M., Stevanović, T., Kostić, Z. (2023). The relationship analysis between environmental performance and economic value of the company. *Facta Universitatis, Series: Economics and Organization,* pp. 135-149.
17. Porritt, J. (2007). Jonathon Porritt on sustainability. *Director, 61(3),* 94.
18. Robaina, M., Madaleno, M. (2020). The relationship between emissions reduction and financial performance: Are Portuguese companies in a sustainable development path? *Corporate Social Responsibility and Environmental Management*, *27(3)*, pp. 1213-1226.
19. Roy, A., Seungmin, H., Mehdi, T.H. (2021). Environmental performance, environmental management and company valuation. *Journal of Global Responsibility.*

20. Slaper, T.F., Hall, T.J. (2011). The triple bottom line: What is it and how does it work. *Indiana Business Review*, *86(1)*, pp. 4-8.
21. So, Y.Y., Eom, J., Han, I. (2017). Tracing the influence of corporate environmental practices on environmental and financial returns. *Social Science Research Network.*
22. Solovida, G., Latan, H. (2021). Achieving triple bottom line performance: Highlighting the role of social capabilities and environmental management accounting. *Management of Environmental Quality: An International Journal*.
23. Thiago, H.M.P., Henrique, C.M. (2021). People, planet, and profit: A bibliometric analysis of triple bottom line theory. *The Journal of Men's Studies.*
24. Trumpp, C., Guenther, T. (2017). Too little or too much? Exploring U-shaped relationships between corporate environmental performance and corporate financial performance. *Business Strategy and the Environment*, *26(1)*, pp. 49-68.
25. Wagner, M. (2015). The link of environmental and economic performance: Drivers and limitations of sustainability integration. *Journal of Business Research, 68(6)*, pp. 1306-1317.
26. Walecka-Jankowska, K., Mrzygłocka-Chojnacka, J. (2023a). Relationship between environmental innovation and sustainable outcomes: Empirical evidence from Denmark. *Ekonomia-Wroclaw Economic Review*, *29(3)*, pp. 99-112.
27. Walecka-Jankowska, K., Mrzygłocka-Chojnacka, J. (2023b). Relationship between environmental innovation and sustainable outcomes – Empirical evidence from Poland. *Zeszyty Naukowe Politechniki Śląskiej. Seria Organizacji i Zarządzanie*, *170*.
28. Zgrzywa-Ziemak, A. (2019). *Model zrównoważenia przedsiębiorstwa*. Wrocław: Oficyna Wydawnicza Politechniki Wrocławskiej.

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MANAGEMENT OF THE RESTRUCTURING PROCESS IN ROAD TRANSPORT OF GOODS ENTERPRISES

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Purpose: The aim of this article is to discuss the issues surrounding the management of restructuring processes and to illustrate the scale of the problem in the road freight transport industry.
Design/methodology/approach: The article presents figures for the restructuring of companies in the country and compares the performance of the industry against the overall performance.
Findings: Companies undergoing restructuring processes are those at risk of bankruptcy. In the vast majority, the choice of restructuring method falls on one of the four possible ones, i.e., proceedings for approval of an arrangement.
Research limitations/implications: The years from 2020 to 2023 and the first quarter of 2024 were analysed.
Practical implications: The analysis of the problem and the statistics on restructuring proceedings show that companies need to redraft their strategy and implement management methods to assess the risk of crisis on an ongoing basis.
Originality/value: The article is aimed at the road freight transport industry, with the aim of raising awareness of the risk of bankruptcy and presenting options for avoiding it.
Keywords: Restructuring, transport companies, risk of bankruptcy.
Category of the paper: Research paper.

1. Introduction

Restructuring is a process sanctioned by the Restructuring Law of 15 May 2015. The fundamental purpose of the Act is to implement effective instruments to avoid the declaration of bankruptcy by a company (Prawo restrukturyzacyjne, Dz.U.2022.2309). The Restructuring Law thus enables business entities, to implement legally sanctioned restructuring processes aimed at overcoming the crisis of a company (Zaremba, 2021). The unstable economic situation in the country and in the world forces companies to adapt to extreme conditions of functioning on the market and, in frequent cases, to undertake actions with the features of a fight for survival (Raczkowski, 2023). In economic practice, for many

entities, restructuring has become the only way to restore balance and escape the finality of bankruptcy.

2. The role and background of restructuring in the company

By their very nature, businesses are oriented towards achieving specific goals. Perturbations in the environment cause these goals to become unrealistic in the current conditions, which prevents entities from achieving the assumed economic results and forces changes in individual spheres of activity and often in the overall corporate strategy (Rojek, 2016). There are many different definitions of restructuring in the literature. Depending on the approach and on the context in which it is carried out, the definition of restructuring has seen different renditions. Examples of definitions are presented in Table 1.

Table 1.
Definition of restructuring

Author	Definition
R. Borowiecki	"Restructuring is a process of radical changes to economic structures, which are implied both by transformations in the sphere of the mechanisms of functioning of economies and by the desire to shape new paths for the development of enterprises in order to increase their efficiency and competitiveness on the market" (Borowiecki, Jaki, 2015).
A. Stabryła	"Restructuring is a diagnostic and design procedure aimed at improving a company's management and operating systems, with the changes relating primarily to the transformation of organisational form, management decision-making systems and human resources" (Stabryła, 1996).
V. Srivastava, G. Mushtaq	"Restructuring is a significant change in a company's strategy. A fundamental and fundamental change that responds to major changes within the company and in its environment" (Srivastava, Mushtaq, 2011).
Z. Pierścionek	"Restructuring is a specific approach to achieving and maintaining a company's competitiveness and growth. Its most important objective is to permanently reduce manufacturing costs by reducing labour costs, reducing inefficient products and markets, introducing relatively new technologies and management structures" (Pierścionek, 2006).
A. Nalepa	"Restructuring of a company means a deliberate reorientation of the company's objectives (mission) in line with changes in the environment that have occurred or are expected to occur in the future, and the adaptation of technology, organisation, economics and personnel to this" (Nalepa, 1998).
K. Wanielista, I. Miłkowska	„Restructuring is a process of systemic changes: property, organisational, economic, financial, technical, adapted to the effective realisation of the company's objectives" (Wanielista, Miłkowska, 1998).

Restructuring, globally speaking, focuses on radical change and is therefore often the only solution a company can apply to combat a crisis (Kaczmarek, 2018). As can be seen from the definitions in the table, change must accompany restructuring processes and most often refers to a fundamental change in the company's overall operations aimed at improving financial performance and increasing competitiveness. Restructuring in a company should take place at

the operational and/or strategic level. The characteristics of restructuring are presented in Table 2.

Table 2.
The characteristics of restructuring

Type	Operational restructuring	Strategic restructuring
Purpose	improvement of the financial situation, Improving solvency	increasing the investment attractiveness of the company, expanding opportunities to attract external financing enterprise value growth
Methods	reduction in production costs, staff reduction, inventory, suspension of capital construction, implementation of work in progress, sale of subsidiaries, sale of unused equipment and materials, debt restructuring, accounts receivable optimization, renewal of fixed assets, introduction of modern management technologies	merger (acquisition, accession), strategic alliance, sale of part of the enterprise or withdrawal of investments, outsourcing, capital splitting, creation of subsidiaries, split-off, split-up, voluntary liquidation, privatization
Tasks	adjustment of the solvency of the enterprise in the short term; increasing the investment attractiveness of the enterprise	increasing the net present value stream of future income; enterprise competitiveness growth; increase in the market value of equity

Źródło: Bondarenko, Ivanchenkova, Okhrimenko, Zybareva, Karpitskaya, Huz, 2020, p. 15.

As can be seen from the table, operational restructuring differs from strategic restructuring both in terms of objectives and methods used. Strategic restructuring requires a much longer implementation time, so it will not always work in the face of rapid changes in the environment, in which case the company should initially focus on changes, especially in the operational sphere. Companies with a fundamental problem of loss of liquidity opt for financial restructuring, which is mainly based on renegotiating debt repayment terms, restructuring loans, or converting debt into equity instruments.

Depending on the situation, companies can opt for ad hoc or forward-looking restructuring. In the former case, it will be concerned with ensuring survival in the near term, while in the latter case, restructuring requires much more time and manifests itself in the creation of conditions for the long-term development of the company (Goranczewski, Puciato, 2009). Another classification divides restructuring into restorative and developmental. Restructuring can affect different areas of the company and thus have effects in changes in marketing, resources, organisation, finances, or ownership structure. The scope and types of restructuring are shown in Figure 1.

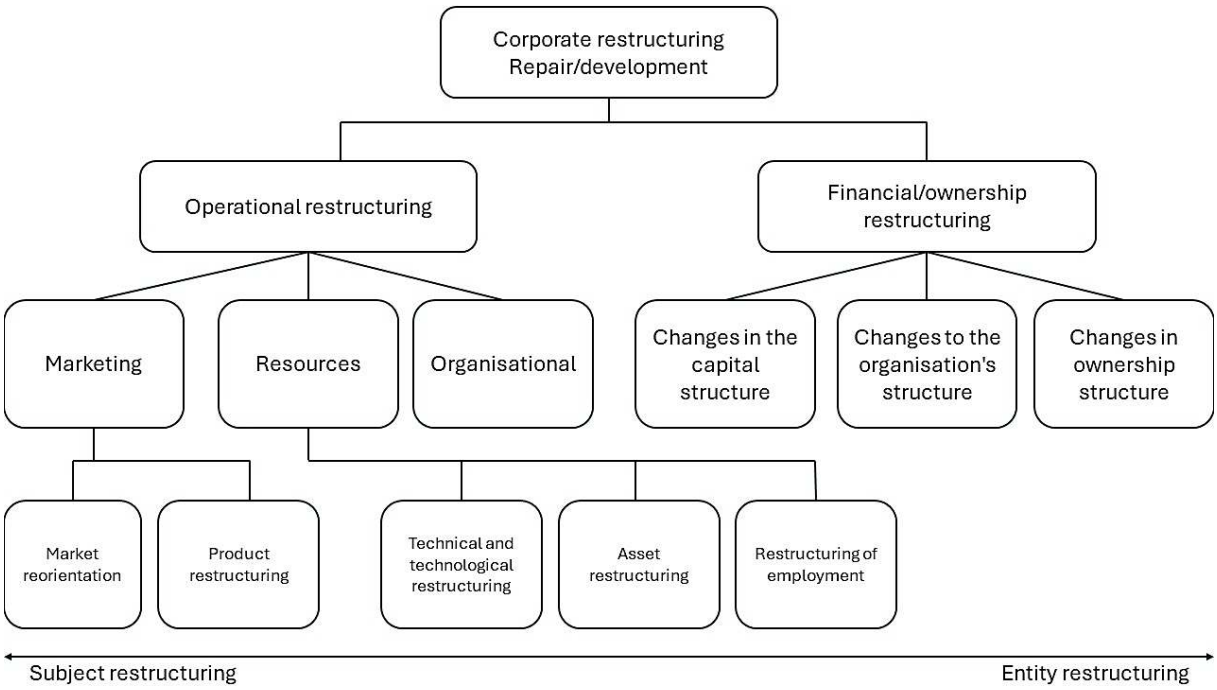

Figure 1. The scope and types of restructuring of the company.

Źródło: Mozalewski, 2010, p. 217.

Operational restructuring concerns the implementation of changes in the company's current operations and is ultimately oriented towards products, technology, assets, employment, and the management system. Financial or ownership restructuring will focus on changes to the financing and ownership structure of the company (Mozalewski, 2010).

The choice of the method and tools of restructuring determines its success. Companies face the difficult task of deciding on the direction of restructuring and selecting effective restructuring methods. In economic practice, there is no universal restructuring model that individuals can use in making such decisions. Restructuring processes must be individually tailored to the needs and situation of the company (Niebieszczańska, 2014).

The need for restructuring arises from the emergence of a crisis situation in the company. A crisis situation is defined as a set of different circumstances that, in the absence of specific corrective measures, will eventually lead to a crisis. As a result of the emergence of a crisis situation, destabilisation in the functioning of the enterprise is perceived, leading to bankruptcy (Wieczerzyńska, 2009). Crisis is thus a consequence of the emergence of a crisis situation and is certainly a huge threat to the existence of the enterprise (Klepka, 2013). Crisis is defined as an intensification of negative phenomena, in the face of which it becomes impossible to perform the basic functions of the enterprise, there is a kind of contradiction between the goals of the enterprise and the resources it has (Barczak, Bartusik, 2010). A crisis in an enterprise may have economic-financial, social, management grounds, and may also concern individual elements of the enterprise (Siciński, 2021). Another approach treats crisis in the context of five stages leading to insolvency, such as strategy crisis, profitability, turnover, liquidity, and insolvency (Kaczmarek, 2018). Crisis in a company can occur in various forms, it can occur as a result of

a sudden emergency caused, for example, by a pandemic, outbreak of war or natural disaster, or it can be the result of slowly growing, unnoticeable business problems (Raczkowski, 2023). In order to efficiently and effectively carry out the restructuring process, the company must objectively diagnose the situation and assess what type of crisis it is facing. Irrespective of the type of crisis, however, a company planning restructuring should also focus on the objective of improving its financial situation.

Different decisions and different restructuring methods will be taken by a company in the case of an acute crisis and different in the case of a crisis resulting from a normal business cycle. There are many tools that enable a company to prepare for a crisis that does not arise suddenly. Early warning systems, controlling, ongoing analysis of the company's financial situation, certainly reduce the risk and make it possible to effectively combat emerging problems. A crisis that appears suddenly is certainly a major challenge for a company, if only because of the need to act under time pressure and in uncertain conditions. Natural disasters, pandemics and wars are situations that companies cannot foresee, and it is therefore difficult to prepare for their consequences. Regardless of the time and situation, restructuring should always take place as a process consisting of five individual phases (Marciniak, 2016):

1. Identification of the reason for restructuring.
2. Selection procedure and definition of the restructuring objective.
3. Stages of restructuring – implementation of the process (assumed tasks).
4. Analysis and assessment of the result of restructuring – the concept of a development strategy.
5. Functioning of the company after restructuring.

The first stage involves the use of forecasting methods, market analyses and market research. Portfolio methods or SWOT analysis will be useful here. The second stage should result from the analyses carried out and be based on standard management methods. In order to correctly identify the purpose and objectives of restructuring, the unit must analyse both the interior of the company and the environment in which it operates. Operational and strategic controlling methods can be used for the assessment. Operational controlling methods can include, but are not limited to cost accounting, income statement, BEP analysis, 4P analysis, risk analysis, quality circles, bottleneck analysis. Strategic controlling focuses on scenario techniques, portfolio methods, also uses the strategic gap and SWOT and PEST (Marciniak, 2016). Restructuring implementation is the executive stage, and here again the classic management functions from planning, organising, motivating, and controlling the tasks performed will work. The fourth stage most often makes use of tools such as Benchmarking, efficiency methods, quality assessment, so that the implemented applications are reflected in the functioning of the company for years to come. For the company's management, the key stages will be the second and third, in which a recovery plan is defined, often involving radical changes to the entire management system. Within the framework of short-term restructuring measures, the most common include, among others: reduction of receivables, reduction of

inventories, reduction of fixed costs, rationalisation of employment, streamlining of work organisation, suspension of investments, reduction of expenses, liquidation, or merger of organisational units (Raczkowski, 2023). However, companies are not always ready to carry out restructuring and, as a result, do not achieve the intended effects. The most common mistakes made in restructuring processes include (Bondarenko et al., 2020):

- wrong choice of type of restructuring,
- lack of complete preliminary diagnosis of the situation,
- incorrect assessment of resources at hand,
- lack of specific objectives for restructuring,
- negative social consequences,
- premature termination of changes,
- changes taking too long,
- lack of experienced leadership.

3. Methods of restructuring road transport companies

Transport companies are a very important link contributing to the economy. They perform three essential functions, consumption, production, and integration (Rudzińska et al., 2009). According to the report 'Road transport in Poland 2023' in 2022, transport accounted for 7% of GDP. Recent changes in the market economy, both legal and induced by the effects of global events, pose major challenges for transport. In order to cope with these challenges and ensure their survival on the market, transport companies have to take the decision to restructure, as this may be the only form of protection against bankruptcy.

Currently, the most common problems, and at the same time reasons for restructuring transport companies, are unequal competition with carriers from Ukraine and the increase in costs generated by the European Union - mobility package, replacement of tachographs, e-CRM (https://continuum.biz.pl/restrukturyzacja-firmy-transportowej). High fuel prices, strict driver working time standards, a shortage of professional drivers, high fleet maintenance costs, payment bottlenecks and low margins also add to the problems of transport companies. Currently, those deciding to restructure a company in accordance with established law have a choice of four types of sub-proceedings (Restructuring Law):

1. The procedure for the approval of the arrangement.
2. Accelerated arrangement procedure.
3. Arrangement procedure.
4. Sanitation proceedings.

The procedure for approval of an arrangement was introduced in 2021 along the lines of the simplified restructuring in connection with COVID-19. In this procedure as one, the proceedings are opened by the restructuring adviser and not by the Court. This greatly simplifies the procedures and enables the entire procedure to run more smoothly. The procedure for approval of the arrangement protects the company from enforcement and also from the risk of termination of key contracts, while being in the procedure it is also possible to unblock the seized bank account (https://kpr-restrukturyzacja.pl). The accelerated arrangement procedure requires the creation of an arrangement plan. Here, the procedures also take place under the guidance of a restructuring advisor. The plan includes a creditors' vote and measures to suspend enforcement proceedings. Arrangement proceedings are possible only when a list of claims has been drawn up and approved and may be conducted if the sum of disputed claims exceeds 15% of the sum of claims entitling to vote on the arrangement. The final sanctioning procedure allows the debtor to carry out sanctioning measures and to conclude an arrangement once the list of claims has been drawn up and approved. According to the Act, 'sanitation actions are legal and factual actions that aim to improve the economic situation of the debtor and are aimed at restoring the debtor's ability to perform its obligations, while protecting it from enforcement'(Restructuring Law). According to data from the Central Economic Information Centre, the road freight transport industry has been at the forefront of restructured companies over the last four years. Detailed data on the number of restructurings of road freight transport companies against the background of the PKD sector - Transport and warehousing are presented in Table 3.

Table 3.
Corporate restructuring in numbers – 2020-2024

Corporate restructuring	2020	2021	2022	2023	2024 (I quarter)
Total	800	1888	2379	4244	1166
Transport and storage section H PKD	76	115	241	513	176
Road freight transport 49.41.Z	47	87	184	423	153

Source: Own elaboration based on data from the Central Economic Information Centre, https://www.coig.com.pl/.

The data in the table show that the problems of road freight transport companies clearly translate into statistics on the restructuring of these companies. As can be seen from the data contained in the COIG reports, in the aforementioned period, the road freight transport industry is ranked second in 2020-2022, and first on the list of restructured companies in 2023-2024, while among all sectors of the economy it also ranks in the lead and so in 2020 - 5th place, 2021 - 6th, 2022 and 2023 - 4th place and 2nd place in the first quarter of 2024.

The COIG data shows that companies definitely opt for the arrangement approval procedure. The statistics on the choice of companies in terms of the type of restructuring proceedings are presented in Table 4.

Table 4.
Types of restructuring proceedings in numbers, in 2020-2024

Type of procedure	2020	2021	2022	2023	2024 (I quarter)
simplified procedure for approval of an arrangement	392	1632			
Proceedings for approval of an arrangement	12	5	2155	3919	1085
accelerated arrangement proceedings	227	132	100	158	40
reorganization proceedings	125	82	91	101	25
arrangement proceedings	14	37	33	54	10
Proceedings for change of arrangement				12	6

Source: Own elaboration based on data from the Central Economic Information Centre, https://www.coig.com.pl/.

It is clear from the reports that companies, with the exception of the period when the 'covidium shields' allowing simplified proceedings were still in operation, are resolutely opting for proceedings to approve the arrangement. Between 2022 and 2024, this procedure accounts for more than 90 per cent of total restructuring proceedings.

To raise the profile of the problem, it is also worth looking at the statistics of companies that have initiated insolvency proceedings. The share of insolvencies of companies in the road freight transport sector and industry is shown in Table 5.

Table 5.
Corporate bankruptcies in numbers – in 2020-2024

Corporate bankruptcies	2020	2021	2022	2023	2024 (I quarter)
Total	587	412	360	408	112
Transport and storage section H PKD	42	18	20	14	7
Road freight transport 49.41.Z	28	9	7	12	5

Source: Own elaboration based on data from the Central Economic Information Centre, https://www.coig.com.pl/.

As can be seen, the number of insolvency proceedings, especially between 2021 and 2024, deviates significantly from the number of restructuring proceedings. Nevertheless, the data shows that transport companies are still an industry at risk of bankruptcy. In this classification at the level of general data contained in the reports of the Central Economic Information Centre, transport is also at the forefront in both the PKD section and the industry.

It is positive that restructuring proceedings predominate, which means that the Restructuring Law has enabled companies to successfully fight for survival. There are no statistics on this, but analysing the data from 2016 to 2020, i.e., since restructuring was introduced, the number of insolvencies has been decreasing in relation to the period before the Restructuring Law, in line with the increase in the number of restructurings. There is therefore no reason to believe that this trend would reverse in the current years.

Unfortunately, the transport market is not a stable market these days, due to both the political and economic situation in the country and the world. The pace and direction of restructuring and insolvency processes is shown in Figure 1.

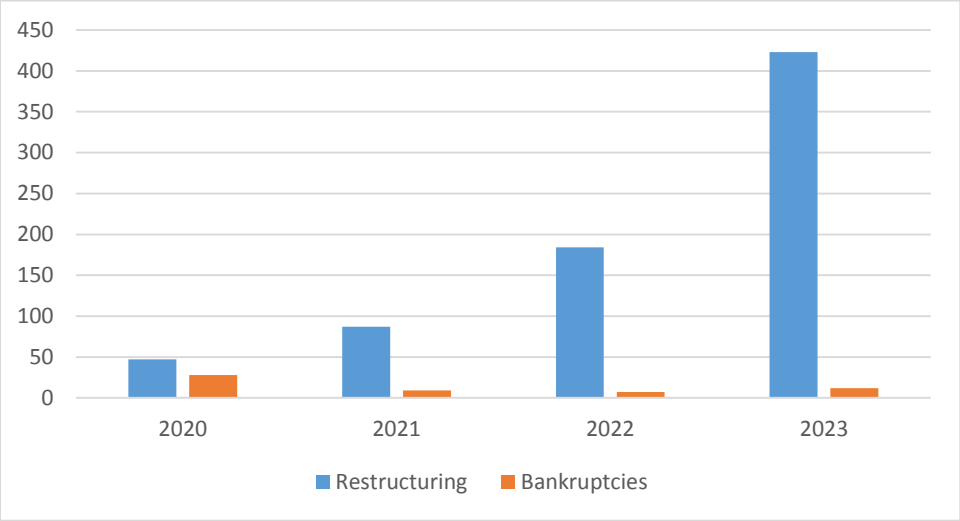

Figure 1. Restructuring and bankruptcies of road freight transport companies between 2020 and 2023.

Source: Own elaboration based on data from the Central Economic Information Centre, https://www.coig.com.pl/.

The figures speak for themselves, but the graphic illustration gives a clear picture of the situation in the road haulage market. Companies, in their struggle to survive and develop, must therefore keep a close eye on the market and adapt their strategy to the current circumstances, both external and internal.

Building an effective strategy under conditions of restructuring is certainly a challenge for the management of road haulage companies. One of the elements of carrying out company restructuring is the creation of a restructuring plan. The restructuring plan is, by definition, intended to lead to a recovery from the crisis and must therefore include tools for increasing the company's efficiency and improving its economic performance. Particular attention should be paid to problems related to management, especially the efficient use of resources in the broad sense. Such resources may include energy resources and energy, space and space, materials and raw materials, human capital, and environmental resources (Pawlowska et al., 2017). Road freight transport companies should focus on increasing efficiency by implementing solutions to optimise logistics or transport infrastructure management. Spatial planning, better transport networks, avoiding so-called 'empty transports', as well as analysing and getting rid of inefficient resources and processes. Efficiency improvements are only possible based on the ability to objectively assess a company's situation and the ability to measure key parameters. The efficiency of transport companies is defined in two dimensions, as the quantity and quality of transport services provided and the monetary value of these services. The assessment of the quantity of quality and value of the transport services provided allows for a technical-operational and economic-financial assessment of the company's operations, respectively

(Wojewódzka-Król et al., 2016). In order to plan restructuring measures, it is necessary to plan corrective actions aimed at increasing economic efficiency, expressed by a set of metrics reflecting the situation of the company in specific areas. Examples of metrics to help determine efficiency in transport companies are presented in Table 6.

Table 6.
Indicators for measuring management performance in transport companies.

Areas of the company	Indicator	Indicator description
Operating	$K = K\text{ł} + Ko$	Mileage rate of the vehicles involved, where: Fang – loading course, Ko – Empty waveform
	$B = \frac{K\text{ł}}{K}$	Mileage utilization rate, where: Tusk – loading course, K – mileage of the vehicles involved
	$C = \frac{Qi}{qi}$	Payload utilization rate, where: Qi – Charge Weight, Qi – vehicle load capacity
	$Tp = Tj + Tr$	Rolling stock operating time indicator, where: Tj – driving time, Tr – stop time
	$Td = \frac{Tp}{De}$	Indicator of the daily working time, where: Tp – rolling stock working time, De – average daily working time
	$F = \frac{Tj}{Tp}$	Vehicle time utilisation rate where: Tj – driving time, Tp – rolling stock working time
Marketing	$Sp = \frac{Lpn}{Lnd}$	Buyer acquisition rate, where: LPN – number of acquired buyers, Lnd – number of existing buyers
	$Su = \frac{Lun}{Lnd}$	Buyer retention rate, where: Lur – number of retained buyers
Economic and financial	$Zd = \frac{Zob}{Aog}$	Debt ratio, where: See – Total liabilities, Aog – Total Assets
	$CR = \frac{Aog}{Zob\ kr}$	Current liquidity ratio, where: See cor – Current liabilities
	$Qr = \frac{\acute{S}r\ p}{Zb}$	Cash ratio, where: Wed p – cash and other monetary assets, ZB – Current Liabilities
	$Rop = \frac{Zn\ op}{Ps\ op}$	Operating return on sales where: Zn op – net profit from operating activities, Ps op – revenues from the sale of operating activities
	$Rm = \frac{Zn}{Aog}$	Return on assets ratio, where: Zn – Net profit, Aog – Total Assets

Cont. table 6.

Human resources	$At = \frac{Dgt}{Di}$	Technical readiness indicator, where: Dgt – Ready Carriers, Di – inventory wagon trucks
	$Awt = \frac{De}{Di}$	Rolling stock utilisation rate, where: De – Operation Vehicles, Di – inventory wagon trucks
	$Agt = \frac{De}{Dgt}$	Utilisation rate of technically ready rolling stock, where: De – Operation Vehicles, Dgt – Ready Carriers
	$Pz = \frac{Ps}{Zt}$	Employment income ratio, where: Ps – sales revenues, Zt – average level of employment
	$Wp = \frac{P}{Zt}$	Work Productivity Index where: P – production level, Zt – average level of employment
	$Zp = \frac{Zn}{Zt}$	Profitability ratio where: Zn – Net profit, Zt – average level of employment

Source: Own elaboration based on: Letkiewicz, 2006; Gabrusewicz, 2014.

The table presents a set of selected indicators / yardsticks that are essential in assessing performance during the restructuring process. The greatest specificity is seen in the operational sphere. Here the focus should be on the efficiency of rolling stock utilisation. An analysis of vehicle mileage, vehicle payload utilisation, as well as working time and its utilisation makes it possible to assess the reasonableness of the fleet owned, but above all the quality of management of this sphere of the company. In marketing activities during restructuring processes, particular attention should be paid to issues related to maintaining the customer base and acquiring new customers, in order to ensure the implementation of operational activities and avoid a reduction in operational efficiency indicators. The economic and financial sphere is assessed through universal financial analysis tools. A restructured company should continuously assess the improvement of indicators that are the cause of restructuring. Debt analysis as well as liquidity and profitability resulting from the measures taken. The issue of employment is also important. Indicators of rolling stock utilisation or technical readiness characterise the company's resources on the one hand, and on the other the quality of work and the level of maintenance servicing the technical and operational facilities. To this should be added measures describing how the level of employment translates into revenues and profits for the company.

The metrics presented in the table can provide a starting point in managing restructuring processes, but the process of managing a company is an extremely individual one and tailored to the needs and situation of the company. Companies should, therefore, individually shape the evaluation metrics in such a way that they highlight problem areas and make it possible to assess the changes brought about by the course of the restructuring process. Undoubtedly, the measures must relate to the indicated areas of activity, operational, marketing, financial and employment.

4. Summary

The management problems in road freight transport companies are certainly many. The basic premise of a company's strategy should be not to allow a situation in which a decision to restructure has to be taken. Market changes and an unstable economy often mean that, despite their efforts, companies are unable to stay in business, lose stability and liquidity, which for all operators is a serious symptom of the crisis. The most common problems for transport companies in recent years have been caused by rising fuel prices, increasing vehicle maintenance costs and a decline in demand for transport services largely due to the growing number of restructurings and bankruptcies in the industrial, construction and agricultural sectors.

The increasing number of transport companies undertaking restructuring proceedings, demonstrates the weakness of this market and its high sensitivity to market changes. These companies in these times, therefore, should pay particular attention to establishing a business management system and building a viable strategy based on detailed market analyses and an objective assessment of their own resources and capabilities. This is key to surviving in a turbulent market and, if necessary, reacting in a timely manner in order to avoid bankruptcy. A crisis situation that leads to bankruptcy can therefore be resolved by implementing restructuring. Whether a company has the capacity to restructure is determined by current conditions and legal aspects, while the problem lies in the preparation and course of the process, namely in the development and implementation of corrective measures. In the sphere of planning restructuring activities, the management level of the company plays a key role. The effectiveness of the analysis and evaluation of the economic situation in the face of the company's situation is a determinant of the success of the entire restructuring process and saving the company from the ultimate eventuality, which is declaring bankruptcy.

References

1. Barczak, B., Bartusik, K. (2010). Kryzys w przedsiębiorstwie w kontekście aktualnych uwarunkowań gospodarczych. In*:* A. Stabryła (ed.), *Zarządzanie w kryzysie.* Kraków: Mfiles.pl.
2. Bondarenko, S., Ivanchenkova, L., Okhrimenko, O., Zybareva, O., Karpitskaya, M., Huz, M. (2020). Risk management of enterprise restructuring strategy. *International Journal of Advanced Research in Engineering and Technology (IJARET), 11(5)*, pp. 14-25.
3. Borowiecki, R., Jaki, A. (2015). Restrukturyzacja – od transformacji do globalizacji. *Przegląd Organizacji, 9*, pp. 4-9.

4. Gabrusewicz, W. (2014). *Analiza finansowa przedsiębiorstwa. Teoria i zastosowanie*. Warszawa: PWE, pp. 296-297.
5. Goranczewski, B., Puciato, D. (2009). Metody usprawniania przedsiębiorstw w trudnej sytuacji finansowej. *Współczesne Zarządzanie*, *3*, pp. 81-90.
6. Kaczmarek, P. (2018). Rola zarządzania ryzykiem w restrukturyzacji przedsiębiorstwa. *Zarządzanie i Finanse*, *16(4/1)*.
7. Klepka, R.N. (2013). Kryzys w przedsiębiorstwie, jego symptomy i przyczyny. *Studia i Materiały. Miscellanea Oeconomicae*, *2*.
8. Letkiewicz, A. (2006). *Gospodarowanie w transporcie samochodowym: wybrane zagadnienia*. Gdańsk: Wydawnictwo Uniwersytetu Gdańskiego.
9. Marciniak, S. (2016). Restrukturyzacja przedsiębiorstw a paradygmaty ekonomii. *Przegląd Organizacji*, *10*.
10. Mozalewski, M. (2010). Metodyka przeprowadzania restrukturyzacji przedsiębiorstw. *Ruch prawniczy, ekonomiczny i socjologiczny, ROK LXXII, z. 2.*
11. Nalepka, A. (1998). *Zarys problematyki restrukturyzacji przedsiębiorstw*. Antykwa.
12. Niebieszczańska, W. (2014). Rola restrukturyzacji naprawczej w postępowaniu upadłościowym przedsiębiorstwa. *Studia Ekonomiczne*, *198*, pp.155-169.
13. Pierścionek, Z. (2006). *Strategie konkurencji i rozwoju przedsiębiorstwa*. Warszawa: PWN.
14. Raczkowski, K. (2023). *Restrukturyzacja przedsiębiorstw. W poszukiwaniu wartości aktywów.* Warszawa: Uniwersytet Kardynała Stefana Wyszyńskiego w Warszawie.
15. Rojek, T. (2016). Wykorzystanie narzędzi restrukturyzacji w procesie zarządzania efektywnością przedsiębiorstwa. *Studia Oeconomica Posnaniensia*, *4(2)*, pp. 135-154.
16. Siciński, J. (2021). *System wczesnego ostrzegania przedsiębiorstw przed ryzykiem upadłości na przykładzie branży transportowej*. Sopot: Centrum Myśli Strategicznych.
17. Srivastava, V., Mushtaq, G. (2011). Restrukturyzacja przedsiębiorstwa – strategia finansowa. *Azjatycki Dziennik Badań nad Technologią i Zarządzaniem*, *1(1)*.
18. Stabryła, A. (1996). *Zarządzanie rozwojem firmy*. Akademia Ekonomiczna. Katowice: Wydawnictwo Uczelniane.
19. Ustawa z dnia 15 maja 2015 r. Prawo restrukturyzacyjne, Dz.U.2022.2309.
20. Wanielista, K., Miłkowska, I. (1998). *Słownik menedżera*. Fraktal.
21. Wieczerzyńska, B. (2009). *Kryzys w przedsiębiorstwie*. Warszawa: CeDeWu.
22. Wojewódzka-Król, K., Załoga, E. (2016). *Transport: nowe wyzwania*. Warszawa: PWN.
23. Wróblewski, R. (2010). Wybrane problemy zarządzania przedsiębiorstwem w sytuacjach kryzysowych. *Zeszyty Naukowe Uniwersytetu Przyrodniczo-Humanistycznego w Siedlcach, Seria: Administracja i Zarządzanie*, *87*, pp. 49-66.
24. Zaremba, U. (2021). *Restrukturyzacja sądowa a upadłość przedsiębiorstw w Polsce*. Warszawa/Rzeszów: Oficyna Wydawnicza Aspra.

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EU PROGRAMS AS A TOOL FOR ENHANCING UNIVERSITY POTENTIAL IN RESPONSE TO SOCIAL AND EDUCATIONAL TRANSFORMATIONS

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Purpose: the article aims to highlight the influence of projects co-financed by the European Union on university development and the enhancement of their educational offerings.
Design/methodology/approach: the study employed traditional literature review methods and explored publicly available information sources. The collected data underwent critical evaluation, followed by a synthesis of findings using a deductive approach.
Findings: 1. Revolution 5.0 emphasizes the importance of integrating technology and humanistic values in education, personal life and work, calling on universities to adapt by fostering social competencies and using advanced technologies. 2. EU programs such as POWER and FERS play a key role in supporting universities by funding infrastructure, technology and staff development, enabling them to meet the demands of rapid technological and social change without overburdening their budgets. 3. Through the strategic use of EU funds, universities can streamline educational programs and implement large-scale projects that would otherwise be financially unattainable.
Originality/value: drawing the attention of those responsible for university management to: the need to change the approach to the educational process, which requires combining advanced technological skills with social skills, and the need for universities to participate in FERS programs in order to relieve the burden on their own budgets and focus on areas with the greatest potential for development.
Keywords: Education 5.0, EU projects, universities, public management.
Category of the paper: viewpoint.

1. Introduction

As two interpenetrating sectors, the contemporary higher education system and the labour market are constantly facing new challenges. Technological development, generational differences (e.g., in the teacher-student or boss-employee relationship), and the changing demand for key competencies influence modern education.

At the stage of Industry 4.0, which focused on process improvements and efficiency, higher education faced numerous challenges, including the ongoing digital transformation. According to P. Chmielecki, the challenges in the education sector should also include aspects related to the need for professionalisation of study programs and the phenomenon of staff degradation (Chmielecki, 2021). The expression of the education sector's challenges is Education 4.0, which responds to the transformations occurring in the industry. It requires universities to apply advanced technologies and automation in educational processes and to prepare students to function in a society of ubiquitous digital technologies (Juszczyk, 2023). Universities are therefore faced with the necessity not only to implement new technologies, including information and communication technologies, but also to handle them smoothly and integrate them into didactic, research, and managerial processes (Mazurek, 2019).

Although many publications are devoted to Industry 4.0 and its impact on transformations in various sectors, Industry 5.0 and Education 5.0 are already on the horizon, bringing new challenges for institutions involved in the education process. These changes will require greater adaptation and innovation to meet growing demands and dynamically changing realities. Technological progress and its subsequent transformations, along with the resulting social and educational changes, are reflected in the available EU programs. These programs give universities a better chance of preparing for upcoming challenges without fully burdening their budgets.

2. Technological transformation and its impact on social and educational change

One of the primary driving forces of progress has been the pursuit of reducing human effort in work. This drive, associated with emerging new technologies that significantly impact economic growth, production, and lifestyle changes, is called the Industrial Revolution (Mathur et al., 2022). Currently, five industrial revolutions are distinguished, each influencing not only industry but also education and society.

Following industrial revolutions, transformations occur in other sectors as well, such as Health 4.0 (Al-Jaroodi et al., 2020), which marks a shift from mass, reactive patient care to individualised, proactive healthcare (Bagaria, 2020); Construction 4.0, which involves the adaptation of industrial principles and technologies to the entire supply and value chain in the construction sector (Nagy et al., 2021); or the already mentioned Education 4.0 (Mukul, Büyüközkan, 2023). The table below (Tab. 1) succinctly captures the impact of technological progress on industry, education, and society.

Table 1.
Impact of technological progress on industry, education, and society

Revolution	Technology	Industry	Education	Society
1.0 - industrial	Mechanical production, steam power	The transition from an agrarian economy to an industry using steam to mechanise production and transportation	1.0—essentialised: a process based on the unilateral transfer of knowledge to a small group of students. The teacher has full authority over the class, students remain passive, and knowledge is given by the teacher and then reproduced by the student	1.0 Hunter-gatherer: a group of people engaged in gathering or hunting
2.0 - technological	Electricity, assembly line (automotive development, among others), internal combustion engine production	Electrification of production facilities, mass production	2.0 Education system based on testing knowledge through exams	2.0 Agricultural: a group of people leading a sedentary lifestyle focused on farming
3.0 - digital	Computer systems, electronics	Automation of production	3.0 Teacher acts as a facilitator, a guide in the learning process using digital tools to transfer knowledge. Methods used: project problems, cooperative learning, global projects	3.0 Industrial: a hierarchical society divided into social classes
4.0 - Internet/ information	IoT (internet of things), cloud computing, AI (artificial intelligence), among others	Emergence of smart factories using digital technologies to create intelligent products and processes	4.0 Use of modern technologies in the teaching process, use of Internet resources	4.0 Informational: significant technology impact on daily life (e.g., use of technology in daily communication)
5.0 - intelligent manufacturing	Digital twins, advanced data analysis, AI (artificial intelligence) development, among others	Two dimensions: 1. Collaboration between robots and humans (interpenetration of the virtual and real worlds) 2. Ensuring a balance between the environment, industry and economics with sustainability in mind	5.0 Emphasises the importance of social and emotional students development putting emphasis on the results achieved	5.0 Human-centered society that uses technology and automation to meet the challenges of the 21st century

Source: Grądzki, 2021, p. 139; Pilevari, Yavari, 2020, pp. 44-51, Kalaichelvan, Subramanin, 2023, pp. 52-55; Vall, 2019, pp. 13-18; Heijden, 2023.

Technological evolution drives significant changes in industry and society. Emerging technologies, manifested as industrial revolutions, have a profound impact on shaping the world. Each industrial revolution builds upon the achievements of its predecessors, creating

a foundation for subsequent transformations. Technological advancements inevitably bring about changes in education and society.

Similar to the Industrial Revolution 5.0, the concept of Education 5.0 is emerging in the academic sphere. This relatively new concept is evidenced by the limited number of articles addressing the topic in the Scopus database—only fourteen were published between 2019 and 2022 (Andres et al., 2022). Although industrial revolutions do not fully align with educational revolutions, the relationship with societal transformations remains debated.

For instance, Professor M. du Vall identifies Society 1.0 as a community of hunter-gatherers that transitioned into a sedentary, agriculture-centered society (Society 2.0) (Vall, 2019). Other researchers (e.g., Turečková et al., 2023) consider the birth of Society 1.0 to coincide with the first industrial revolution, marked by the transition from an agriculture-based economy to an industrial economy powered by steam energy. Subsequent technological transformations fostered the development of industrial Society 3.0, followed by information-driven Society 4.0 (Ferreira, Serpa, 2018).

In the literature, Society 4.0 is also referred to as a digital or smart society. Its defining characteristic is the seamless integration of technology, automation, and digitalisation into various aspects of life (Turečková et al., 2023). On the foundations of the extensively described 4.0 revolutions, 5.0 revolutions are being shaped. Society 5.0 is defined as a data-driven society leveraging technological advancements to improve quality of life and address social challenges (Yunindanova, 2022).

Generational changes also reflect societal transformations. Generation Z, comprising individuals born after 1995, has distinct expectations and preferences compared to previous generations. Education 5.0 integrates advanced technologies like artificial intelligence with collaborative (cooperative) learning and practical experiences. This new era in education emphasises the importance of leveraging modern technologies in the learning process while focusing on developing social skills, such as critical thinking, interdisciplinary problem-solving, and adaptability to rapidly changing environments (Shahidi Hamedani et al., 2024).

Addressing the challenges posed by the Social and Educational Revolution 5.0 requires organisational and personal flexibility and financial investment. Many initiatives support the organisational development of universities within the framework of projects and programs co-financed by the European Union.

3. Support within EU Programs

One of the European Union's primary financial instruments has been the European Social Fund (ESF), aimed at supporting employment, social development, and enhancing social and economic cohesion within member states. In Poland, the ESF has been implemented through

Operational Programs, the most well-known of which is the Operational Program Knowledge Education Development (PO WER). This program focused on providing support in the areas of education, employment, and social integration. Another program, implemented at the regional level and aimed at local development, is the Regional Operational Programs (RPO). For the 2021-2027 financial perspective, the European Social Fund has been replaced by the European Fund for Social Development (pol. FERS/ang. ESF+), which continues the objectives of the ESF while placing greater emphasis on the European Union's current priorities, such as the green transition, digitalisation, and social equality and inclusion.

The goals of the European Social Fund and its successor, the European Fund for Social Development, are embedded in the core documents and strategic frameworks of the European Union. Among the most significant are:

- The Treaty on the Functioning of the European Union (TFEU): article 162 specifies that the ESF aims to promote economic, social, and territorial cohesion within the European Union.
- The European Union's Strategy: currently, the EU's Strategic Agenda for 2024-2029 is in effect. This document outlines three priorities: a free and democratic Europe, a strong and secure Europe, and a prosperous and competitive Europe. The latter focuses on increasing competitiveness, fostering green and digital transitions, promoting an innovation-friendly environment, and driving joint progress. The strategy emphasises investment in human skills, lifelong learning, and education while encouraging talent mobility within and beyond the EU.
- Transforming Our World: The 2030 Agenda for Sustainable Development: adopted in 2015 by the United Nations, this agenda calls for member states to focus on eradicating poverty in all its forms while achieving economic, social, and environmental goals. It sets 17 Sustainable Development Goals (SDGs) with 169 associated tasks. The fourth goal, directly linked to education quality, is to "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all". Within this goal, seven specific targets are to be achieved by 2030. Poland's response to the agenda is the Strategy for Responsible Development, which aims to create conditions for increasing citizens' income while fostering social, economic, and environmental cohesion. This strategy places people at its centre, emphasising human and social capital as the key to achieving its three detailed objectives.
- The European Green Deal: presented in 2019, the Green Deal encompasses legislative proposals related to ecological transformation, including climate, energy, transport, and tax policies. The European Green Deal envisions the EU becoming the world's first climate-neutral region by 2050. It aims to reduce pollution and restore a healthy balance in nature and ecosystems.

The European Social Fund (ESF) program and the European Fund for Social Development (FERS) are part of the established policies of the European Union. Thanks to funding from these funds, among others, higher education institutions can modernise their curricula, support teaching staff and students, and introduce innovative solutions adapted to the requirements of the modern world and minimise generational differences in technological aspects, speed of obtaining information, or teaching/learning models.

4. Support from EU funds to enhance university potential

Below is a characterisation of the activities of three public universities related to the implementation of projects co-financed by EU funds. The review focused on the top three universities listed in the "Academic Universities Ranking 2024" published on the Perspektywy website (these universities have consistently maintained their top positions). The analysis utilised this ranking due to its significant role in influencing prospective students' choices of higher education institutions. Additionally, the ranking considers key areas of academic activity, such as research, quality of education, internationalisation, and innovation.

The analysis covered projects acquired over the past five years, examining their funding sources, project objectives, and budgets. Selected projects focused on enhancing teaching competencies and were therefore targeted at the academic community. The universities are characterised below in the order of their ranking, starting with the top-ranked academic university in 2024.

4.1. University of Warsaw (UW)

Project name: program of integrated actions for the University of Warsaw development.
Source: Operational Program Knowledge Education Development (POWER).
Duration: 2.04.2018- 31.12.2023.
Budget: 41 239 759,83 PLN.
Objective: to develop and implement mechanisms aimed at teaching excellence and improving university management processes.
Beneficiaries: 9,159 individuals (including 5,368 students, 894 doctoral candidates, and 2,897 administrative and managerial staff).
Key Activities/Outcomes:

- introduction of new study programs supporting interdisciplinary research projects and English-language programs,
- IT initiatives, such as the creation of the SAD browser for integrating educational data,

- a wide range of specialised training and workshops focusing on soft skills for university staff, including the UW Deans' Academy (management skills support), language courses, soft skills workshops, and specialised training such as computer courses,
- a comprehensive offering of courses for students, covering areas such as digital skills, analytical competencies, and entrepreneurship.

Project name: Teaching excellence of universities.
Source: Operational Program Knowledge Education Development (POWER) + the Ministry of Education and Science - Excellence in University Teaching.
Duration: academic year 2022/2023.
Budget: 711,730 PLN.
Objective: To support organisational changes, improve the quality of teaching, and enhance processes and tools for ensuring teaching quality.
Beneficiaries: approximately 370 academic teachers and administrative staff.
Key Activities/Outcomes:

- establishment of a quality teaching advisory point in the office of educational innovation, serving a consultative and advisory role,
- creation of a best practices database, including examples related to teaching innovation,
- development of the Deans' Collaboration Platform, a resource compiling diverse materials on the teaching process,
- introduction of new tools for evaluating teaching activities,
- training sessions for academic teachers to enhance their competencies.

Project name: University for Everyone - Level Up.
Source: Operational Program Knowledge Education Development (POWER).
Duration: 01.2020-09.2023.
Budget: 14,977,739.70 PLN.
Objective: to enhance existing and develop innovative solutions to increase the accessibility of education for individuals with disabilities at the UW.
Beneficiaries: students with disabilities, teaching staff, and administrative personnel.
Key Activities/Outcomes:

- acquisition of 3 specialised buses to ensure accessible transportation,
- equipping the main library, selected departmental libraries, and laboratories with specialised equipment to improve independence in studying and working for individuals with disabilities,
- dissemination of knowledge and standards related to accessibility (training sessions for UW staff to raise awareness about removing barriers in studying and working for individuals with disabilities),

- launching a tactile maps laboratory for visually impaired individuals,
- expansion of the eBON system with new functionalities,
- reconstruction of the passageway at the UW, including the installation of an elevator.

4.2. Jagiellonian University in Krakow

Within the framework of the IntegratedUJ strategic project, the university is implementing two projects, Key to the future - Comprehensive program for the development of education to meet the needs of UJ's key industries, and Teaching Engagement Development (TED) - University teachers and doctoral students facing the challenges of the future.

Project name: Key to the Future - Comprehensive Program for Developing Education for Key Industries at Jagiellonian University.

Source: European Social Fund Plus, European Funds for Social Development (FERS).

Duration: 01.01.2024 – 30.06.2029.

Budget: 21,856,519.74 PLN (18,036,000.09 PLN from the EU).

Objective: to adapt the Jagiellonian University's educational offerings to meet the needs of economic development and green and digital transformation by developing study programs aimed at training future professionals for key industries, such as renewable energy, agriculture and food production, aerospace, and transportation.

Beneficiaries: 1,334 individuals (1,185 students and 149 faculty members of Jagiellonian University).

Key Activities/Outcomes:

- modification of existing or creation of new educational programs across 8 faculties,
- additional initiatives for students, including study visits, training, internship programs, and measures to reduce the phenomenon of early dropout in project-covered fields of study,
- improving the qualifications of academic teachers involved in teaching new or modified programs, particularly in areas such as digital skills, green transformation, and universal design.

Project name: Teaching Engagement Development (TED): Academic Teachers and Doctoral Candidates Facing Future Challenges.

Source: European Social Fund Plus, European Funds for Social Development (FERS).

Duration: 01.01.2024 – 30.06.2029.

Budget: 9 002 537,50 PLN (7 428 893,95 PLN from the UE).

Objective: to adapt the university's offerings to the needs of economic development and green and digital transformation by implementing initiatives to enhance the qualifications and competencies of teaching staff (including doctoral candidates) in the areas of teaching (including the use of modern teaching methods and methodologies), digital transformation, and green transformation.

Beneficiaries: 620 individuals (120 doctoral candidates, 500 academic staff members from Jagiellonian University).
Key Activities/Outcomes:
Activities for doctoral candidates:

- mandatory participation in three training sessions on teaching competencies, three sessions on digital skills, one session on awareness and skills development for green transformation, and one session on entrepreneurship, commercialisation of research outcomes, and other substantive competencies (a total of 80 teaching hours),
- after completing the training, additional support includes domestic and international internships as well as study visits.

Activities for academic staff:

- mandatory training in three areas: teaching, digital transformation, and green transformation,
- after completing the mandatory training, participants can join specialised training such as Academic Teaching Excellence, Intercultural Communication, and subject-specific courses,
- support also includes international internships, study visits, and mentoring involving individual training sessions.

Project name: Excellent University – Education for the Economy.
Source: European Funds for Social Development (FERS).
Duration: 1.07.2024 – 1.01.2029.
Budget: 34 615 484,74 PLN (28 564 698,01 PLN from the EU).
Objective: o develop the educational offerings of Jagiellonian University to meet the needs of the economy, labor market, and green and digital transformation through the implementation of a comprehensive support program for students and teaching staff.
Beneficiaries: students and teaching staff.
Key Activities/Outcomes:

- creation of new or modification of existing educational programs across 13 faculties in collaboration with employers, practitioners, and other entities operating in the socio-economic environment,
- implementation of additional educational components, including practical elements,
- measures aimed at reducing the phenomenon of early dropout from studies,
- development of qualifications and competencies of teaching staff through participation in courses, training sessions, internships, and study visits.

Project name: Responsible Support and Sustainable Development.
Source: Operational Program Knowledge Education Development (POWER).
Duration: 01.2020-10.2023.
Budget: 11 127 813,14 PLN (10 793 978,74 PLN from the EU).
Objective: to enhance the accessibility of Jagiellonian University for individuals with permanent or temporary disabilities, limited mobility due to age, or health conditions resulting from illnesses or accidents.
Beneficiaries: approximately 440 staff members.
Key Activities/Outcomes:

- training sessions for staff on university accessibility for people with disabilities, as well as training for students on stress management, note-taking, and maintaining life balance,
- adapting the building of the Jagiellonian University Teaching Support Center to meet the needs of individuals with disabilities,
- establishment of a council for responsible support and sustainable development,
- updating university websites and e-learning courses to comply with WCAG 2.1 accessibility standards,
- creation of an educational portal for people with disabilities,
- development of a navigation and information application and website for individuals with disabilities,
- creation of an application and website with sign language translation for lectures,
- implementation of a remote examination system for individuals with significant disabilities,
- purchase of evacuation chairs for people with disabilities.

Project name: Excellent University – Integrated Development Program of Jagiellonian University.
Source: Operational Program Knowledge Education Development (POWER).
Duration: 01.04.2019-31.12.2023.
Budget: 18 951 003,28 PLN (15 971 905,56 PLN from the EU).
Objective: to improve the quality of education, operations, and management at Jagiellonian University through the implementation of the Integrated University Development Program. The program focuses on adapting undergraduate and graduate study programs, enhancing the professional and language competencies of students and staff, supporting IT tools for university and teaching process management, creating open knowledge resources, and improving information management to enhance the quality of education at the university.
Beneficiaries: 1,878 individuals (1,278 students and 600 staff members).

Key Activities/Outcomes:

- adapting undergraduate and graduate study programs,
- enhancing professional and language competencies among students and staff,
- implementing IT tools for university and teaching process management numbering.

4.3. Warsaw University of Technology (WUT)

As part of the strategic project "Science - Education - Development - Cooperation," Warsaw University of Technology (WUT) implemented two projects that overlapped in terms of duration and scope of tasks: NERW PW and NERW 2 PW. The goal of both projects was to improve the functioning of Warsaw University of Technology in education and management, as well as to adapt the university's educational offerings to labor market needs by implementing a comprehensive program of actions focused on student-centered education.
Project name: Science - Education - Development - Cooperation PW.
Source: Operational Program Knowledge Education Development (POWER).
Duration: 01.02.2018-31.10.2022.
Budget: 37 985 430,39 PLN (32 014 120,73 PLN from the EU).
Beneficiaries: academic teachers, administrative and managerial staff, students.
Key Activities/Outcomes: 55 tasks within 4 action modules, including:

- establishment of 12 videoconferencing rooms to enhance educational activities,
- launch of new or modification of existing educational programs,
- student participation in training, courses, and workshops to improve professional, language, communication, entrepreneurial, and analytical skills,
- enhancement of academic teachers' teaching competencies and managerial and administrative staff's management skills through training and teaching internships,
- development of the SEZAM system and expansion of open educational resources (including the Industry 4.0 Platform).

Project name: Science - Education - Development - Cooperation 2 PW.
Source: Operational Program Knowledge Education Development (POWER).
Duration: 03.03.2019-31.12.2023.
Budget: 35 604 550,08 PLN (z 30 007 514,81PLN from the EU).
Beneficiaries: 2,767 individuals (exceeding the planned 2,053), including 331 staff members, 2,251 students, and 187 doctoral candidates.

Key Activities/Outcomes:
39 tasks within 6 modules, including:

- launch of new or modification of existing educational programs,
- improvement of students' competencies in professional, language, communication, entrepreneurial, and analytical skills through participation in training sessions, study visits, and PBL (Problem-Based Learning) activities,
- participation in internships by 210 students,
- conducting social research related to the quality of education and alignment of educational offerings with current needs,
- establishment of a Doctoral School,
- enhancement of academic teachers' teaching competencies and managerial and administrative staff's management, modern teaching, language, and IT skills through participation in training sessions, postgraduate studies, and study-training visits,
- development and integration of existing systems with newly implemented ones, such as USOS (University Study-Oriented System), Eduroam, and the Electronic Document Workflow system.

Project name: OMNIS – Openness. Modernisation. Innovation. Integration. Community/
Source: Operational Program Knowledge Education Development (POWER), Action 1.5/
Duration: 01.01.2024-28.02.2029/
Budget: 14 075 881,02 PLN (11 615 417,02 PLN from the EU)/
Objective: to adapt the educational offerings of Warsaw University of Technology to labor market needs in key industries such as renewable energy, aerospace, agriculture and food production, and transportation, while enhancing the competitiveness of the university's graduates/
Beneficiaries: students and academic teachers/
Key Activities/Outcomes:

- modifications of educational programs in collaboration with practitioners and entities from the socio-economic environment,
- participation of students in additional educational components such as training sessions or courses, study visits, extra classes conducted by industry specialists, or remedial classes,
- initiatives aimed at reducing the phenomenon of early school leaving,
- enhancement of teaching staff's competencies in digital skills, awareness and skills for green transformation, universal design, and modern teaching methods through participation in training sessions, courses, study visits, internships, and other forms of support.

Project Name: OMNIS2 – Openness. Modernisation. Innovation. Integration. Community.
Source: European Funds for Social Development 2021-2027 (FERS).
Duration: 01.05.2024 – 30.06.2029.
Budget: 17 362 058,12 zł (14 327 170,36 zł z UE).
Objective: to adapt the educational offerings of Warsaw University of Technology to labor market needs by implementing a comprehensive program of actions aimed at delivering modern, student-centered education that also addresses the requirements of the socio-economic environment.
Beneficiaries: 956 individuals, including students and academic teachers.
Key Activities/Outcomes:

- modification of educational programs in collaboration with practitioners and entities from the socio-economic environment,
- additional educational components such as training sessions/courses, extra classes conducted by industry specialists, and study visits for students,
- initiatives to reduce the phenomenon of early dropout, including remedial classes for students and efforts to recruit informed candidates,
- enhancement of teaching staff's competencies in areas such as digital skills, awareness, and skills for green transformation, as well as teaching competencies, including the use of modern teaching methods and methodologies. These improvements are facilitated through training sessions, courses, study visits, and teaching internships.

Over the past five years, the University of Warsaw, Jagiellonian University, and Warsaw University of Technology have implemented numerous projects funded by the European Union. These projects aimed to enhance the quality of teaching by developing new technologies, implementing new procedures, adapting infrastructure, and enriching academic and administrative staff competencies.

The execution of EU co-funded projects has facilitated the adaptation of study programs to labour market needs, the introduction of innovative teaching methods, and the development of digital tools to improve the educational process. Thanks to these initiatives, which have also helped ease the financial burden on their own budgets, these universities have consistently maintained top positions in academic rankings.

5. Summary

Revolution 5.0 highlights the necessity of integrating humans and technology across personal life, professional environments, and the educational process. Once again, universities must embrace flexibility, innovation, and adaptation to new challenges. Transformations associated with 5.0 not only advocate the use of advanced technologies, such as artificial

intelligence, but also emphasise the humanistic dimension of education, underlining the importance of developing social competencies.

EU programs, such as the previously implemented POWER (Operational Program Knowledge, Education, Development) and the current FERS (European Funds for Social Development), along with their associated initiatives, can serve as crucial support tools for universities in adapting to the demands of 5.0. These programs, rooted in EU policies like fostering a knowledge-based economy, enable universities to invest in infrastructure, new technologies, staff development, and the enhancement of educational programs.

As a result, universities are better positioned to respond effectively to the challenges posed by dynamic social and technological changes, while minimising the use of their own resources. The cases of three leading universities have exemplified this.

University budgets are often insufficient to meet the demands of technological revolutions. EU funds enable the implementation of additional initiatives that enhance educational programs and modernisation projects that would otherwise be financially out of reach for universities. This allows institutions to focus their financial resources on fulfilling their educational, research, and social missions or to diversify their portfolios to significantly reduce the burden on their own funds.

References

1. Al-Jaroodi, J., Mohamed, N., Abukhousa, E. (2020). Health 4.0: On the Way to Realizing the Healthcare of the Future. *IEEE Access*, *Vol. 8*, pp. 211189-211210, doi: 0.1109/ACCESS.2020.3038858
2. Andres, B., Sempere, F., Esteso, A., Alemany, M.M.E. (4-6.07.2022). Mapping between Industry 5.0 and Education 5.0. *EDULEARN22 Proceedings*, pp. 2922, doi: 10.21125/edulearn.2022.0739
3. Bagaria, N., Laamarti, F., Badawi, H.F., Albraikan, A., Martinez Velazquez, R., El Saddik, A. (2020). Health 4.0: Digital Twins for Health and Well-Being. In: A. El Saddik, M. Hossain, B. Kantarci (Eds.), *Connected Health in Smart Cities* (p. 144). Cham: Springer.
4. Chmielecki, P. (2021). Czy dzisiejszy uniwersytet hoduje troglodytów? Etyczne implikacje przemian szkolnictwa wyższego. *Edukacja Ustawiczna Dorosłych*, *No. 1(112),* p. 26, doi: 10.34866/446e-q263
5. Czaban, M., Janiak-Jasińska, A., Jaworska, B., Rosińska, A., Sas, M., Sempruch, G. *Kalejdoskop Programu ZiP*. Retrieved from: https://zip.uw.edu.pl/sites/default/files/content/kalejdoskop-programu-zip_publikacja-2024.pdf
6. *Doskonałość dydaktyczna uczelni*. Retrieved from: https://www.uw.edu.pl/doskonalosc-dydaktyczna-uczelni/?utm_source=chatgpt.com, 31.10.2024.

7. *European Council, Strategic Agenda 2024-2029*. Retrieved from: https://www.consilium.europa.eu/media/yxrc05pz/sn02167en24_web.pdf, 31.10.2024.
8. Ferreira, C., Serpa, S. (2018). Society 5.0 and Social Development: Contributions to a Discussion. *Management and Organisational Studies, Vol. 5, No. 4*, pp. 26, doi:10.5430/mos.v5n4p26.
9. Forcael, E., Ferrari, I., Opazo-Vega, A., Pulido-Arcas, J.A. (2020). Construction 4.0: A Literature Review. *Sustainability, Vol. 12(22), 9755,* pp. 4-7, doi:10.3390/su12229755.
10. Grądzki, W. (2021). Portal edukacyjny szansą rozwoju zdalnej edukacji Grądzki. In: A. Lukasek, A. Fidelus (Eds.), *Funkcjonowanie dziecka we współczesnym świecie. Współpraca z rodziną. Wyzwania, zagrożenia, perspektywy* (p. 139). Józefów: Wydawnictwo Wyższej Szkoły Gospodarki Euroregionalnej im. Alcide De Gasperi w Józefowie.
11. Heijden, J. (2023). Construction 4.0 in a narrow and broad sense: A systematic and comprehensive literature review. *Building and Environment, Vol. 244*. Retrieved from: https://doi.org/10.1016/j.buildenv.2023.110788.
12. Juszczyk, J. (2023).Funkcjonowanie młodzieży w świecie postcyfrowym na podstawie wielodyscyplinowych badań w ramach paradygmatów: Przemysł 4.0, Edukacja 4.0 oraz Społeczeństwo 5.0. In: E. Widawska (Ed.), *Młode pokolenie w (nie)przyjaznym świecie - konteksty teoretyczne, metodologiczne i praktyczne* (pp. 159-162). Kraków: ATW.
13. Kalaichelvan, R., Subramanin, P. (2023). Historical perspective of education 1.0 to education 5.0. In: S. Prakash, M.A. Muniammal, M.Maruthavanan, S. Raja Kumar, K. Thangavel, N. Sundar (Eds.), *Education 5.0: Revolutionizing Learning for the Future* (pp. 52-55). Madurai: Internal Quality Assurance Cell (IQAC).
14. *Key to the future - Kompleksowy program rozwoju kształcenia na potrzeby branż kluczowych UJ*. Retrieved from: https://key.zintegruj.uj.edu.pl/, 31.10.2024.
15. Mathur, A., Dabas, A., Sharma, N. (2022). *Evolution From Industry 1.0 to Industry 5.0*. 4th International Conference on Advances in Computing, Communication Control and Networking (ICAC3N), Greater Noida, India.
16. Mazurek, G. (2019). Transformacja cyfrowa - perspektywa instytucji szkolnictwa wyższego. In: J. Woźnicki (Ed.), *Transformacja Akademickiego Szkolnictwa Wyższego w Polsce w okresie 30-lecia 1989-2019* (pp. 16, 328). Warszawa: KRASP.
17. Mukul, E., Büyüközkan, G. (2023). Digital transformation in education: A systematic review of education 4.0. *Technological Forecasting and Social Change, Vol. 194, 122664*, Retrieved from: https://doi.org/10.1016/j.techfore.2023.122664.
18. Nagy, O., Papp, I., Szabó, R.Z. (2021). Construction 4.0 Organisational Level Challenges and Solutions. *Sustainability, Vol. 13(21), 12321*, p. 1, doi:10.3390/su132112321.
19. *NERW PW*. Retrieved from: https://www.nerw.pw.edu.pl/O-projektach, 31.10.2024.
20. *Odpowiedzialne wsparcie i zrównoważony rozwój Uniwersytet Jagielloński*. Retrieved from: https://przelamuj.uj.edu.pl/pl, 31.10.2024.

21. *OMNIS – Strona główna projektu.* Retrieved from: https://cpr.pw.edu.pl/projekty-realizowane/omnis-aktualnosci/, 31.10.2024.
22. *OMNIS2 – Informacje o projekcie.* Retrieved from: https://cpr.pw.edu.pl/projekty-realizowane/omnis2-aktualnosci/omnis2-informacje-o-projekcie/, 31.10.2024.
23. Organizacja Narodów Zjednoczonych. Rezolucja przyjęta przez Zgromadzenie Ogólne w dniu 25 września 2015 r., Przekształcamy nasz świat: Agenda na rzecz zrównoważonego rozwoju 2030.
24. Pilevari, N., Yavari, D. (2020). Industry Revolutions Development from Industry 1.0 to Industry 5.0 in Manufacturing. *Journal of Industrial Strategic Management, Vol. 5, Iss. 2*, pp. 44-51.
25. *Projekt Doskonały Uniwersytet – kształcenie dla gospodarki, realizowany w latach 2024-2029*. Retrieved from: https://doskonaly.uj.edu.pl/o-projekcie, 31.10.2024.
26. *Ranking Uczelni Akademickich 2024*. Retrieved from: https://2024.ranking.perspektywy.pl/ranking/ranking-uczelni-akademickich, 31.10.2024.
27. Raschke, S.U. (2022). Limb Prostheses: Industry 1.0 to 4.0: Perspectives on Technological Advances in Prosthetic Care. *Front. Rehabil Sci., Vol. 3*, p. 2, doi: 10.3389/fresc.2022.854404.
28. Shahidi Hamedani, S., Aslam, S., Mundher Oraibi, B.A., Wah, Y.B., Shahidi Hamedani, S. (2024). Transitioning towards Tomorrow's Workforce: Education 5.0 in the Landscape of Society 5.0: A Systematic Literature Review. *Education Sciences, Vol. 14, Iss. 10*, p. 2. Retrieved from: https://doi.org/10.3390/educsci14101041.
29. *Teaching Engagement Development (TED): Nauczyciele akademiccy i doktoranci wobec wyzwań przyszłości*. Retrieved from: https://ted.zintegruj.uj.edu.pl/, 31.10.2024.
30. Turečková, K., Nevima, J., Vaňová, A., Vitálišová, K. (2023). Society 4.0: general economic implications. *Journal of European Economy, Vol. 22, No. 2(85),* p. 150. Retrieved from: https://doi.org/10.35774/jee2023.02.146.
31. Vall, M. (2019). Super inteligentne społeczeństwo skoncentrowane na ludziach, czyli o idei społeczeństwa 5.0 słów kilka. *Państwo i Społeczeństwo, Iss. 2,* pp. 14, 13-18, doi: 10.34697/2451-0858-pis-2019-2-001.
32. Yunindanova, M.B. (2022). Preparing for Indonesian Agricultural Transformation in The Society Era 5.0. *Agrosains: Jurnal Penelitian Agronomi, Vol. 24, No. 1*, pp. 32-36. Retrieved from: https://doi.org/10.20961/agsjpa.v24i1.59741.

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CAREER CHARACTERISTICS OF WOMEN SATISFIED WITH THEIR JOBS

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Purpose: The aim of this study is to create a characterisation of the careers of women satisfied with their work.
Design/methodology/approach: The quantitative study was conducted by survey (CAWI) using an online questionnaire on a sample of 517 women. The questionnaire included single and multiple choice, open-ended questions. The survey lasted 9 months (February-October 2022) and included economically active women working in medium or large enterprises in south-eastern Poland. Responses were elicited through a 'snowball' effect and invitations to participate in the survey sent to organisations meeting the criteria. Statistical analysis included descriptive characteristics and tests of intergroup comparisons.
Findings: On the basis of the research carried out and the results obtained, it is possible to indicate the characteristics of the professional career of a woman demonstrating satisfaction with her work. She is a woman aged 35, with children and living in the Małopolskie Voivodeship. She is employed as an independent specialist or holds an executive position in health care, services or financial activities and earns more than 10 500 PLN gross per month. She has significant professional experience gained in her previous work in three different organisations. Her professional career is of great importance to her and she ensures its regular development by taking courses to develop her hard skills and by training independently from her work in the organisation.
Research limitations/implications: The results refer only to the surveyed group, without the possibility of generalisation. The division of female respondents into groups according to job satisfaction may be a simplification that does not take into account the complexity of shades of satisfaction. The research covers only a fragment of the subject of job satisfaction among women, constituting an introduction to further research, e.g. broadening the scope of job satisfaction among women, referring to an aspect other than professional career, examining satisfaction in different regions of Poland or comparing results on a national scale. It would also be interesting to conduct an analogous study among men and analyse gender differences.
Originality/value: In view of such a diverse approach to the topic of job satisfaction, however, there are few Polish studies relating to the context of women's careers, set in the realities of the domestic labour market. Therefore, it seems justified to take up the topic of women's careers demonstrating job satisfaction discussed in the article.
Keywords: job satisfaction, career satisfaction, career, women's career.
Category of the paper: Research paper.

1. Introduction

In today's world, job satisfaction plays a key role in both professional and personal lives, influencing overall happiness and mental health. As the labour market evolves, increasing attention is being paid to the quality of working life and how work fits into the wider life context of employees. Women who find satisfaction in their work are often better able to cope with challenges and are more successful in completing their tasks. Job satisfaction therefore becomes not only an end in itself, but also an important part of building a long-term career. The results of the Women in the Workplace 2023 report show that women who are satisfied with their work are more motivated to take on new challenges and pursue professional development. This attitude also fosters more effective and innovative teams, which ultimately leads to better performance for the organisation as a whole. Analysing the careers of women who are satisfied with their jobs provides insight into what elements of their careers are conducive to success and how they can be supported on their path to professional fulfilment.

Bourezg et al. (2024) studied job satisfaction among women in the Middle East. Yang and Choi (2022) devoted their study to the career orientation and life satisfaction of married women. The impact of race, gender identity and their interaction on career satisfaction was the focus of a study by Pattani et al. (2022). Subsequent researchers have focused on the impact of equity on female managers' perceptions of career prospects and job satisfaction across sectors (Suh, Hijal-Moghrabi, 2022) and women's developmental networks and career satisfaction (Chang et al., 2021). Yusuf and Farradinna (2021) investigated the mediating role of social support in the relationship between responses to workplace bullying and job satisfaction among women, and Kurup et al. (2020) the mediating effects of factors influencing the job satisfaction of female academics in higher education. Patwardhan et al. (2018) studied the factors influencing career advancement and satisfaction of female managers in the Indian hospitality industry. The subject of Chu's (2018) study was work motivation and job-related satisfaction based on a comparison of perceptions of female police officers in Dubai and Taipei. Takawira (2018) analysed the role of career satisfaction-oriented characteristics in women's career development, and Arasu Balasubramanian and Lathabhavan (2018) linked women's beliefs about the glass ceiling to employee satisfaction.

In view of such a diverse approach to the topic of job satisfaction, however, there are few Polish studies relating to the context of women's careers, set in the realities of the domestic labour market. In view of this, it seems justified to take up the topic discussed in the article on the careers of women demonstrating job satisfaction. The aim of this study is to create characteristics of professional careers of women satisfied with their work. In view of such a goal, a research question was formulated referring to what characteristics the careers of women who are satisfied with their work have.

Job satisfaction is a key employee attitude affecting organisational performance. The systematic study of this phenomenon began less than 100 years ago. In the 1930s, at the Hawthorne Western Electric Company plant, a study was conducted on employee wellbeing, referred to as 'sentiment' or 'tone' (Kożusznik, 2007; Wright, Cropanzano, 2007). The term 'job satisfaction' emerged in the 1950s (Wright, 2006), becoming an important part of work and organisational psychology. There are many definitions of job satisfaction (Sowińska, 2014). Locke (1976) defined it as the result of perceiving work to enable the achievement of important values for the individual. Homburg and Stock (2004) describe it as the result of comparing the desired standard of the work environment with the actual one. Aguinis, Henle and Ostroff (2001) and Aydintan and Koc (2016) emphasise the emotional aspect of satisfaction, defining it as an affective response to a work situation. Bubble (2000) sees it as an affective response to tasks performed. Lewicka (2010) sees it as a positive attitude towards duties, colleagues and the work environment.

Job satisfaction includes cognitive, emotional and behavioural aspects (Paliga, 2021). Rakowska and Mącik (2016) distinguish four aspects: physical working conditions, economic working conditions, interpersonal relationships and tasks and activities performed. In the Polish literature, the terms 'job satisfaction' and 'job satisfaction' are often used interchangeably, but the differences may relate to the duration of the experience. Judge and Klinger (2008) argue that the emotional component of satisfaction is short-lived, making it difficult to measure. Zalewska (2003) notes that researchers focus on the cognitive component, neglecting the emotional one. Job satisfaction is divided into general and specific levels. General refers to an individual's attitude towards work, while specific refers to the evaluation of a specific job factor (Sergiovanni, 1966; Zalewska, 2003; Wolowska, 2013). Factors influencing satisfaction include economic aspects, working conditions, interpersonal relationships and tasks performed (Miąsek et al., 2015). Satisfaction assessment should take into account the weight given to each aspect (Paliga, 2021).

Job satisfaction theories are divided into dispositional, situational and interactional theories (Judge et al., 2001). Dispositional theories examine the importance of individual characteristics such as positive and negative affectivity and the five-factor model of personality (Judge, Larsen, 2001). Situational theories focus on the role of organisational factors such as pay, promotion, relationships with colleagues, supervision, recognition, working conditions and management (Smith, Kendall, Hulin, 1969; Locke, 1976; Mendoza, Maldonado, 2014). Management practices and managerial behaviours, such as social support and resources, are important for satisfaction (Brown, Peterson, 1993; Mendoza, Maldonado, 2014). Nguyen et al. (2003) indicate that satisfaction depends not only on absolute income but also on the benchmark. Factors affecting satisfaction include job stability, psychological contract, promotion opportunities, participation in training, working conditions and autonomy (Guest, 2004; Chi, Gursoy, 2009; Squires et al., 2015). Haffer (2015) proposes a model in which organisational capability leads to job satisfaction, which results in organisational commitment among

employees. These potentials include leadership, communication, trust, employee rewards and development, working conditions, the role of managers, ethical standards, interpersonal relationships and talent management. Interactional theories analyse the fit between the individual and the work environment (Locke, 1976; Mottaz, 1986; Muchinsky, Monahan, 1987; Kristof, 1996). Job satisfaction results from the work values important to the individual and provided by the organisation. Supplemental fit refers to the similarity of goals and values, and complementary fit refers to the mutual complementarity of resources (Muchinsky, Monahan, 1987). Mismatches lead to tension and lower job satisfaction.

Career satisfaction reflects how an employee evaluates his or her work situation and is a subjective response to various aspects of his or her job, expressing a sense of personal career success (Marzec, 2011, 2018). Gattiker and Larwood (1986) distinguished several dimensions of career satisfaction, such as success related to position, interpersonal relationships, hierarchy, finances and overall life success. The assessment of this satisfaction is influenced by both contextual and individual factors. Individual factors include expectations, career perceptions, personality traits, age, gender, education level, work experience and life situation (Ng et al., 2005; Wieck et al., 2009). Career satisfaction is also closely related to objective career success, measured by, among other things, salary, position and number of promotions (Marzec, 2018). Key contextual factors influencing career satisfaction include organisational conditions such as organisational atmosphere and culture, career development opportunities, support from superiors and organisational resources (Ng et al., 2005).

Research among business sector employees in Greece and China has shown that career satisfaction is also influenced by professional networking, as it creates opportunities for success both inside and outside the organisation (Bozionelos, Wang, 2006). Marzec (2018) conducted a study on the impact of professional networks on career satisfaction of employees of municipal and community cultural centres. The results of this research showed that there was a positive relationship between professional networks, both internal and external, and career satisfaction. In particular, professional contacts outside the organisation were found to have a strong relationship with job satisfaction.

Zalewska (2009) indicates that gender influences satisfaction with relationships with colleagues, perceived pleasure and tension at work. Men are more satisfied with their relationships with colleagues, feel more pleasure at work and feel less intense and less tension than women (Warat, Kowalska, 2018). Sedlak & Sedlak's National Job Satisfaction Survey (2022) shows that men are slightly more satisfied with their jobs than women, with both groups declaring the same level of engagement at work. The biggest differences concern remuneration, cooperation with the supervisor, autonomy, communication and working conditions, which men rated better. Men declared lower levels of job stress. Women did not rate any aspect of work better than men. Andrade, Westover and Peterson (2019) point out that some studies show that women are more satisfied with their jobs than men, although others suggest no significant differences. Key aspects of satisfaction include extrinsic and intrinsic rewards, work

relationships and work-life balance. Men place more emphasis on extrinsic rewards, which can reduce their satisfaction. Women derive more satisfaction from working in a more senior position, staying in the position longer and feeling more pride in their promotion. Relationships at work are another factor. Research by Kessler, Spector and Gavin (2012) found that female professors in the US and Canada experience greater job satisfaction when it is based on teaching rather than research. Women are more satisfied when the workplace is dominated by women, which may be due to a lower risk of unfair treatment. Work-life balance is also important, especially for women who have to balance work and family life. Despite speculation of higher satisfaction for women, Andrade, Westover and Peterson (2019) show that there are no consistent gender differences in job satisfaction. Relationships at work are more important for women, while men value work-life balance more. Research by Vladisavljević and Perugini (2019) explains the gender paradox of job satisfaction, where women declared higher satisfaction despite poorer working conditions. This is due to lower job expectations. Women are more satisfied with their jobs than men, although exceptions occur in Central and Eastern Europe, where men report higher satisfaction. Differences disappear among women growing up in countries with gender equality. Research confirms that women are more satisfied in work environments where women predominate, while their satisfaction decreases in 'typically male' jobs.

2. Methods

In order to collect empirical data, a quantitative study was conducted using a survey method, the CAWI technique. This study used an online survey questionnaire, created using the Google Forms platform, which used single-choice and multiple-choice questions and an open-ended question format. Some of the questions used a five-point Likert scale, consisting of the answers: "definitely not", "rather not", "hard to say", "rather yes", "definitely yes". The survey consisted of a section of questions on job satisfaction and a metric. The survey was conducted over a nine-month period (February 2022 - October 2022), in the form of disseminating a relevant link to the online survey on the Google Forms platform. In the first instance, organisations and the women working in them were targeted, to which the author had direct access. Then, using a 'snowball' effect, the women taking part in the survey were asked to continue to share the survey with further organisations, thereby inviting further respondents to participate. At the same time, the author popularised the survey through e-mails containing an invitation to take part in the survey, sent to organisations meeting the established sample selection criteria. Organisations were selected on the basis of rankings of medium and large companies, prepared by such portals as: https://nowiny24.pl/ (Golden Hundred of Companies 2021),

https://www.obserwatorium.m alopolska.pl/ (List of 500), https://www.forbes.pl/ (Forbes Diamonds 2021).

The research sample consisted of economically active women (n = 517), currently working in medium or large enterprises, living in two voivodeships: Małopolskie or Podkarpackie. The choice of voivodeships was dictated by their economic diversity, socio-cultural conditions and economic differences. Podkarpackie and Małopolskie Voivodeships are located in the southern part of Poland, which is characterised by a diverse economic structure and level of development. In addition, the choice of Podkarpackie and Małopolskie Voivodeships was also due to the scarcity of previous research on job satisfaction and women's careers in these regions.

Once the empirical material was collected, the data was statistically analysed using descriptive characteristics and intergroup comparison tests - the variables analysed in the study were of two types: quantitative and categorical. Quantitative variables were understood as all responses given by respondents on a five-point Likert scale, and their characteristics included the arithmetic mean, standard deviation, median, first and third quartile values, and minimum and maximum values. This part of the analysis began by dividing the female respondents into two groups depending on their sense of job satisfaction. On the basis of the items related to this question, only those women who answered 'rather yes' or 'definitely yes' in each of the satisfaction-related items were included in the satisfaction group. Such women, satisfied with each of the surveyed aspects of their work, accounted for 21.6% of the surveyed group. After comparisons were made, those results that proved to be statistically significant were selected for presentation and discussion.

3. Results

The women who were satisfied with their jobs tended to be older - their average age was 35.5 years, while the average age of the other group was 33 years. Older women may have more work experience, which influences their greater job satisfaction. Experience can lead to better positions, higher salaries and a greater sense of confidence in their duties. They were also more likely to live in the Małopolskie Voivodeship (67%) than in the Podkarpackie Voivodeship (33%). Higher satisfaction among women from the Małopolskie Voivodeship may be due to better working conditions, greater opportunities for professional development or a better labour market in this region compared to the Podkarpackie Voivodeship. The vast majority of women declaring satisfaction with their work had children (46.2%), while among women dissatisfied with their work, 27.8% had children. Women with children may feel more satisfied with their job if their job allows them to reconcile work and family life, which may be due to more flexible working hours, employer support or better social benefits.

Women declaring a gross monthly salary above PLN 10,500 were more often satisfied with their work (15.1% vs. 2.3%). Women who were dissatisfied with their jobs were more often those earning less than PLN 4500 gross per month. The remuneration amounts that least differentiated the level of job satisfaction among the respondents (with a slight predominance towards dissatisfied women) were the range > PLN 6,000 ≤ 7,500 gross per month (9.4% vs. 9.9%). Higher pay is a strong motivator and can lead to greater job satisfaction. Women earning over PLN 10,500 gross may feel more appreciated and motivated to work.

Women who were satisfied with their work more often held top management positions (7.1% vs. 1.9%), and were more often independent employees or specialists (31.3% vs. 22.7%). Women who were dissatisfied with their work more often worked in executive positions - white-collar (48.4% vs. 38.4%) and blue-collar (8.1% vs. 4%). Women in higher management and specialist positions may feel greater job satisfaction due to greater autonomy, prestige and decision-making opportunities.

Analyzing the organization's activity profile, it can be indicated that women who were satisfied with their work were most often employed in health care and social assistance (20.6%), services (16%), and financial and insurance activities (13.2%). Women who were not satisfied with their jobs most often worked in public administration (19.6%) and education (16%). Industries such as health care or finance may offer better working conditions, more satisfying responsibilities, salary levels and greater opportunities for career development compared to public administration or education.

Women who were satisfied with their job changed their job more often. During their professional activity, they worked on average in 3 different organizations, while those who were dissatisfied worked in 2 different organizations. Women who changed their workplace more often could find more suitable conditions for themselves, which could contribute to their greater satisfaction.

For 91.5% of women who were satisfied with their jobs, their professional career was important or definitely important. Its absolute unimportance was more often declared by women who were dissatisfied with their job (4.4% vs. 0.9%). For women who value their careers, job satisfaction is often higher because they are more committed to their work and strive to achieve their career goals.

Regardless of the level of job satisfaction, all women declared taking actions aimed at developing their professional careers, but these actions were different for each group. Women who were satisfied with their work more often took up courses on developing hard skills (67.9% vs. 46.8%) and took up training conducted independently of their work in the organization (47.2% vs. 34%). Women developing hard skills can increase their value on the labor market, which leads to greater opportunities for promotion and salary increases. Their effectiveness in their current job may also increase, which benefits both them and their employers. Women undertaking training regardless of work can develop skills that are valued in the labor market, which increases their competitiveness and career development

opportunities. Dissatisfied women were more likely to learn foreign languages (39.5% vs 26.4%) and take up internships abroad (5.5% vs 0%). Women learning foreign languages can gain new employment opportunities, both at home and abroad. This can lead to greater career mobility and job opportunities in international companies. Internships abroad can open the door to new, international professional experiences. Women who decide to pursue internships abroad can gain valuable skills and contacts that will help them in their further careers.

4. Discussion

The research results indicate that women who were satisfied with their work were older (average age 35.5 years) compared to the dissatisfied group (average age 33 years). Older women, with more professional experience, are more likely to achieve higher positions, which affects their job satisfaction. This finding is consistent with the literature that highlights work experience as a key factor influencing job satisfaction (Ng et al., 2005; Wieck et al., 2009). As employees increase in experience, they are often promoted, which increases their compensation and sense of value at work (Gattiker, Larwood, 1986). The research noted that women from the Małopolskie Voivodeship were more often satisfied with their work (67%) than those from the Podkarpackie Voivodeship (33%). Better working conditions and the labor market in Małopolska may result in higher professional satisfaction. Similar results were obtained by Suh and Hijal-Moghrabi (2022), who found that the regional context and working conditions have a significant impact on the perception of job satisfaction. Women with children were more satisfied with their jobs (46.2%) than those who did not (27.8%). A job that allows you to reconcile work and family life may increase satisfaction. This observation is consistent with the findings of Yang and Choi (2022), who also pointed out the importance of work flexibility and employer support for married women. Women earning more than PLN 10,500 gross were more satisfied with their jobs (15.1% vs 2.3%), while dissatisfied women more often earned less than PLN 4500. Salary as a strong motivating factor influences job satisfaction, which is consistent with the literature that emphasizes the importance of salary for job satisfaction (Nguyen et al., 2003; Chi, Gursoy, 2009). Women in senior management and specialist positions were more satisfied with their work (7.1% vs 1.9% and 31.3% vs 22.7%). The greater autonomy and prestige of these positions contributes to a higher level of satisfaction, as confirmed by the research of Suh and Hijal-Moghrabi (2022) and Judge et al. (2001). The most satisfied women worked in health care, services and finance, while the dissatisfied women worked in public administration and education. Better working conditions in sectors such as health care and finance can lead to greater satisfaction, as reflected in the literature (Bozionelos, Wang, 2006; Marzec, 2018). Women who were satisfied with their work

were more likely to change employers (an average of 3 different organizations), which allowed them to find more appropriate working conditions. Takawira's (2018) research also highlights the importance of career mobility for career satisfaction. For 91.5% of satisfied women, their professional career was important, which indicates greater commitment to work. Women who value their careers are more committed and satisfied with their work, which is confirmed by research by Marzec (2018) and Wright and Cropanzano (2007). Satisfied women were more likely to take courses on hard skills (67.9% vs. 46.8%) and work-independent training (47.2% vs. 34%). This increases their value in the labor market and opportunities for advancement, which is consistent with the literature on the impact of professional development on job satisfaction (Squires et al., 2015; Paliga, 2021). The research results are largely consistent with the literature on the subject, confirming the importance of age, salary, working conditions, professional mobility and the importance of professional career for job satisfaction. Some aspects, such as the importance of work flexibility and employer support for women with children, are also confirmed in the literature. Differences in job satisfaction across industries and the impact of job change on satisfaction are also consistent with previous research findings.

5. Summary

Based on the research conducted and the results obtained, it is possible to indicate the characteristics of the professional career of a woman who shows satisfaction with her work. She is a 35-year-old woman with children and living in the Małopolskie Voivodeship. She is employed as an independent specialist or holds a position among the management staff, in health care, services or financial activities and earns over PLN 10,500 gross per month. He has significant professional experience gained in his previous work in three different organizations. Her professional career is very important to her, which is why she takes care of its regular development by taking courses developing her hard skills and training conducted independently of her work in the organization.

Professional experience, region of residence, having children, remuneration, job position, industry of employment, frequent changes of workplace, importance of professional career and development activities undertaken - all these elements are important characteristics of the professional careers of women satisfied with their work. Employers who take these factors into account can create more favorable working conditions, attracting and retaining satisfied employees, which ultimately contributes to better organizational efficiency and stability.

The research conducted is not free from limitations. First of all, it should be noted that the obtained results can only be applied to the studied group, without generalization. Dividing the respondents into two groups based on their sense of job satisfaction may introduce some simplifications. This does not take into account the different shades of satisfaction and

dissatisfaction, which may be more complex. The examined aspects do not exhaust the topic of women's job satisfaction, but constitute only a part of it, which can be treated as an introduction to the full research. However, this limitation indicates a possible direction for future research, which could focus on expanding the scope of job satisfaction among women or relating it to an aspect other than professional career. It could also be interesting to examine women's job satisfaction in other regions of Poland and compare the results obtained or conduct research on the entire country. It also seems interesting to conduct a similar study among men and examine differences in job satisfaction resulting from the gender aspect.

References

1. Aguinis, H., Henle, C.A., Ostroff, C. (2001). Measurement in Work and Organizational Psychology. In: N. Anderson, D.S. Ones, H.K. Sinangil, C. Viswesvaran (Eds.), *Handbook of Industrial, Work and Organizational Psychology. Vol. 1. Personnel Psychology*. London: SAGE.
2. Andrade, M.S., Westover, J.H., Peterson, J. (2019). Job Satisfaction and Gender. *Journal of Business Diversity*, *19(3)*.
3. Aydintan, B., Koc, H. (2016). The Relationship between Job Satisfaction and Life Satisfaction: An Empirical Study on Teachers. *International Journal of Business and Social Science*, *7(10)*, pp. 72-80.
4. Balasubramanian, S.A., Lathabhavan, R. (2018). Linking women's glass ceiling beliefs and employee satisfaction: the mediation of engagement. *International Journal of Human Resources Development And Management*, *18(1-2)*, pp. 72-90.
5. Bańka, A. (2000). Psychologia pracy. In: J. Strelau (Ed.), *Psychologia. Podręcznik akademicki, t. 3*. Gdańsk: GWP.
6. Bourezg, M., Khassawneh, O., Singh, S., Mohammad, T., Melhem, M.J., Darwish, T.K. (2024). Exploring the path to job satisfaction among women in the Middle East: a contextual perspective. *Gender in Management: An International Journal*.
7. Bozionelos N., Wang L. (2006). The Relationship of Mentoring and Network Resources with Career Success in the Chinese Organizational Environment. *International Journal of Human Resource Management*, *17(9)*, pp. 1531-1546.
8. Brown, S.P., Peterson, R.A. (1993). Antecedents and Consequences of Salesperson Job Satisfaction: Meta Analysis and Assessment of Causal Effects. *Journal of Marketing Research*, *30*, pp. 63-77.
9. Chang, J., Baek, P., Kim, T. (2021). Women's developmental networks and career satisfaction: Developmental functions as a mediator. *Journal of Career Development*, *48(5)*, pp. 733-750.

10. Chi, C.G., Gursoy, D. (2009). Employee satisfaction, customer satisfaction, and financial performance: An empirical examination. *International Journal of Hospitality Management*, *28(2)*, pp. 245-253.
11. Chu, D.C. (2018). Employment motivation and job-related satisfaction: a comparison of police women's perceptions in Dubai and Taipei. *Policing and Society*, *28(8)*, pp. 915-929.
12. Gattiker U., Larwood L. (1986). Subjective Career Success: A Study of Managers and Support Personnel. *Journal of Business and Psychology*, *1(2)*, pp. 78-94.
13. Guest, D. (2004). Flexible employment contracts, the psychological contract and employee outcomes: an analysis and review of the evidence. *International Journal of Management Reviews, 1(5/6)*.
14. Haffer, R. (2015). Determinanty i następstwa satysfakcji pracowników w świetle teorii pozytywnego zarządzania. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu*, *376*, pp. 152-168.
15. Homburg, C., Stock, R. (2004). The Link Between Salespeople's Job Satisfaction and Customer Satisfaction in a Business to Business Context: A Dyadic Analysis. *Journal of the Academy of Marketing Science*, *32(2)*, pp 144-158.
16. Judge, T.A., Bono, J.E., Thoresen, C.J., Patton, G.K. (2001). The job satisfactionjob performance relationship: A qualitative and quantitative review. *Psychological Bulletin*, *127*, pp. 376-407.
17. Judge, T.A., Klinger, R. (2008). Job satisfaction: Subjective well being at work. In: M. Eid, R.J. Larsen (Eds.), *The science of subjective well being*. New York: Guilford Press.
18. Judge, T.A., Larsen, R.J. (2001). Dispositional affect and job satisfaction: A review and theoretical extension. *Organizational Behavior And Human Decision Processes*, *86(1)*, pp. 67-98.
19. Kessler, S.R., Spector, P.E., Gavin, M.B. (2012). A critical look at ourselves: Do male and female professors respond to the same environment characteristics? *Research in Higher Education*, *55(4)*, pp. 350-361.
20. Kożusznik, B. (2007). *Zachowania człowieka w organizacji*. Warszawa: PWE.
21. Kristof, A.L. (1996). Person organization fit: an integrative review of its conceptualizations. Measurement and implications. *Personnel Psychology*, *49(1)*, pp. 1-49.
22. Kurup, A.J., Pandey, S., Charfare, M. (2020). Mediating effects of factors influencing career satisfaction of women academicians in higher education. *Prabandhan: Indian Journal of Management*, *13(4)*, pp. 7-24.
23. Lewicka, D. (2010). *Zarządzanie kapitałem ludzkim w polskich przedsiębiorstwach*. Warszawa: PWN.
24. Locke, E.A. (1976). Nature and Causes of Job Satisfaction. In: M.D. Dunette (Ed.), *Handbook of Industrial and Organizational Psychology*. Chicago: Rand McNally.

25. Marzec, I. (2011). Klimat uczenia się w organizacji czynnikiem subiektywnego sukcesu zawodowego pracowników. In: M. Pawlak (Ed.), *Nowe tendencje w zarządzaniu – spotkanie teorii z praktyką*. Lublin: Katolicki Uniwersytet Lubelski.
26. Marzec, I. (2018). Sieć kontaktów zawodowych jako czynnik budowania satysfakcji z kariery zawodowej pracowników miejskich i gminnych ośrodków kultury. *Studia Ekonomiczne*, *376*, pp. 135-147.
27. McKinsey & Company (2023). *Women in the Workplace*. Retrieved from: https://www.mckinsey.com/featured-insights/diversity-and-inclusion/women-in-the-workplace#/, 5.07.2024.
28. Mendoza, M.L., Maldonado, C.O. (2014). Meta analytic of the relationship between employee job satisfaction and customer satisfaction. *Suma de Negocios*, *5(11)*, pp. 4-9.
29. Miąsek, P., Żak Łykus, A., Skałacka, K., Nawrat, M. (2015). Różnice międzypłciowe w satysfakcji z pracy i jakości życia wśród przedstawicieli kadry zarządzającej. *Czasopismo Psychologiczne, 21(2)*, pp. 305-310.
30. Mottaz, C. (1986). Gender differences in work satisfaction, work related rewards and values, and the determinants of work satisfaction. *Human Relations*, *39*, pp. 359-378.
31. Muchinsky, P.M., Monahan, C.J. (1987). What is person environment congruence? Supplementary versus complementary models of fit. *Journal of Vocational Behavior*, *31(3)*, pp. 268-277.
32. Ng, T.W.H., Eby, L.T., Sorensen, K.L., Feldman, D.C. (2005). Predictors of Objective and Subjective Career Success: A Meta-Analysis. *Personnel Psychology*, *58*, pp. 367-408.
33. Nguyen, A., Taylor, J., Bradley, S. (2003). Relative Pay and Job Satisfaction. Some New Evidence. *MPRA Paper*, *1382*, pp. 47-59.
34. Paliga, M. (2021). *Satysfakcja z pracy i wydajność pracowników. Relacja (nie) oczekiwana.* Katowice: Wydawnictwo Uniwersytetu Śląskiego.
35. Pattani, R., Burns, K.E., Lorens, E., Straus, S.E., Hawker, G.A. (2022). Effect of race, gender identity, and their intersection on career satisfaction: a cross-sectional survey of academic physicians. *Medical Teacher*, *44(6)*, pp. 614-621.
36. Patwardhan, V., Mayya, S., Joshi, H. (2018). Women managers moving on: What might influence their career advancement and satisfaction in the Indian hotel industry? *Prabandhan: Indian Journal of Management*, *11(12)*, pp. 7-21.
37. Rakowska, A., Mącik, R. (2016). Zaangażowanie pracownika a satysfakcja z pracy—Modelowanie zależności z wykorzystaniem PLS-SEM. *Przegląd organizacji*, *5*, pp. 48-58.
38. Sedlak & Sedlak (2022). *Ogólnopolskie Badanie Satysfakcji z Pracy*. Kraków: Sedlak & Sedlak.
39. Sergiovanni, T. (1966). *Satisfaction and dissatisfaction of teachers: Final report*. Urbana, Illinois: University of Illinois.
40. Smith, P.C., Kendall, L.M., Hulin, C.L. (1969). *The measurement of satisfaction in work and retirement.* Chicago: Rand McNally.

41. Sowińska, A. (2014). Zadowolenie z pracy – problemy definicyjne. *Studia ekonomiczne*, *197*. Uniwersytet Ekonomiczny w Katowicach, pp. 45-56.
42. Squires, J.E., Hoben, M., Linklater, S., Carleton, H.L., Graham, N., Estabrooks, C.A. (2015). Job Satisfaction among Care Aides in Residential Long Term Care: A Systematic Review of Contributing Factors, Both Individual and Organizational. *Nursing Research and Practice*, pp. 1-24.
43. Suh, J., Hijal-Moghrabi, I. (2022). The effects of fairness on female managers' perception of career prospects and job satisfaction: A study across sectors. *International Journal of Public Administration*, *45(8)*, pp. 644-657.
44. Takawira, N. (2018). Career Development of Professional Women: The Role of Person—Centered Characteristics on Career Satisfaction. *Psychology of Retention: Theory, Research and Practice*, pp. 243-262.
45. Vladisavljević, M., Perugini, C. (2018). *Gender inequality and the gender job satisfaction paradox in Europe*. Kunitach: Center for Economic Institutions, Institute of Economic Research, Hitotsubashi University.
46. Warat, M., Kowalska, B. (2018). Równość płci na rynku pracy a jakość życia. In: E. Krzaklewska (Ed.), *Wpływ równości płci na jakość życia i rozwój społeczny w Polsce* (pp. 117-143). Kraków: Wydawnictwo Uniwersytetu Jagiellońskiego.
47. Wieck, K.L., Dols, J., Northam, S. (2009). What Nurses Want: The Nurse Incentives Project. *Nursing Economics*, *27(3)*, pp. 169-179.
48. Wołowska, A. (2013). Satysfakcja z pracy i jej wyznaczniki a poczucie jakości życia urzędników. *Rocznik Andragogiczny*, *20*, pp. 119-132.
49. Wright, T.A. (2006). To be or not to be (happy): The role of employee well being. *Academy of Management Perspectives*, *20*, pp. 118-120.
50. Wright, T.A., Cropanzano, R. (2007). The happy/productive worker thesis revisited. *Research in Personnel and Human Resources Management*, *26*, pp. 269-307.
51. Yang, X., Choi, B.K. (2022). Married women's career orientation and life satisfaction: Role of self- efficacy. *Journal of Employment Counseling*, *59(1)*, pp. 2-16.
52. Yusuf, Y., Farradinna, S. (2021). The Mediating of Social Support on The Relationship Between Bullying Response at Work and Job Satisfaction Among Women Career Indonesia. *Review of International Geographical Education Online*, *11(5)*.
53. Zalewska, A. (2009). Wiek, płeć i stanowisko pracy a zadowolenie z pracy. *Psychologia Jakości Życia*, *1*, pp. 1-20.
54. Zalewska, A.M. (2003). Skala Satysfakcji z Pracy – pomiar poznawczego aspektu ogólnego zadowolenia z pracy. *Acta Universitatis Lodziensis. Folia Psychologica*, *7*, pp. 49-61.

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ANOMALY DETECTION IN UNIVARIATE TIME SERIES USING A MULTI-CRITERIA APPROACH

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Purpose: The purpose of this study is to propose and evaluate a multi-criteria framework for anomaly detection in univariate time series. By integrating various statistical and machine learning techniques, the study aims to enhance the accuracy and robustness of anomaly identification. This approach seeks to address the challenges posed by complex and dynamic datasets, providing a flexible methodology suitable for diverse applications.
Design/methodology/approach: The study employs a multi-criteria approach to anomaly detection in univariate time series. It integrates statistical methods, such as boxplots and deviation-based rules, with machine learning techniques like clustering (hierarchical and k-means). The framework includes three aggregation strategies: restrictive, liberal, and scoring-based, to evaluate anomalies based on different criteria. The methodology is demonstrated using synthetic time series data that incorporates trends, seasonality, noise, and controlled anomalies.
Findings: The study reveals significant differences in the performance of various anomaly detection methods applied to univariate time series. Restrictive approaches provide high specificity, minimizing false positives, while liberal methods are more inclusive but prone to false alarms. The scoring-based approach offers a balanced evaluation, enabling quantification of anomaly significance across multiple criteria. The results demonstrate that combining statistical and machine learning methods enhances detection precision. The proposed multi-criteria framework is adaptable to diverse applications, though further validation on real-world datasets is required to confirm its effectiveness and scalability.
Originality/value: This study introduces a novel multi-criteria framework for anomaly detection in univariate time series, combining statistical and machine learning techniques with aggregation strategies to enhance detection accuracy. Unlike existing approaches, it systematically integrates multiple criteria and evaluates their collective impact on anomaly identification. The framework provides flexibility through restrictive, liberal, and scoring-based methods. Its originality lies in the methodological synthesis and the potential to address complex challenges in anomaly detection across various domains, offering valuable insights for both researchers and practitioners.
Keywords: anomaly detection, outlier detection, univariate time series, multi-criteria analysis.
Category of the paper: research paper, technical paper.

1. Introduction

Anomaly detection is critically important across various domains (Mehrotra et al., 2017), as it enables the identification of atypical, potentially critical events or patterns in data. Such events can signal problems, risks, or even new, unexpected opportunities. The importance of anomaly detection can be considered in several key aspects (Box et al., 2015; Chandol et al., 2009; Mills, 2019; Nielsen, 2019), including:

- Preventing and detecting problems: Identifying equipment failures, irregularities in device performance, network disruptions, early warnings in critical systems, deviations in sensor readings (e.g., in industry, energy, aviation), data protection, and cybersecurity.
- Supporting decision-making processes: Detecting operational inefficiencies, analyzing production or logistics processes to identify anomalies that lead to time or resource losses.
- Managing finance and risk: Detecting financial fraud, unusual transactions, deviations from the planned budget, or anomalies in stock market operations.
- Enhancing safety and quality: Identifying deviations in patients' health parameters (medical field), anomalies in navigation systems, autonomous vehicles, or railways to prevent accidents (transport), as well as improving data quality by detecting errors, missing data, and irregular values.

Anomaly detection plays a pivotal role in improving efficiency, safety, and quality across nearly every aspect of life and business. Rapid identification of deviations enables better decision-making, risk minimization, and the enhancement of business data value. In the context of growing data volume and complexity, automation and fast anomaly detection algorithms have become indispensable tools for modern organizations (Kao, Jiang, 2019).

From a technical perspective, anomaly detection in time series involves identifying data points that significantly deviate from expected patterns, trends, or seasonality observed in historical data. This may include extreme values (outliers), sudden trend changes, unexpected seasonal patterns, or deviations in value distributions (Braei Wagner, 2020; Chandola et al., 2009). The general principle is to identify patterns or a theoretical model of the series and then examine the residual distribution (deviations from the pattern or errors). The core idea is illustrated in Figure 1, which demonstrates time series decomposition using the STL method: Seasonal-Trend Decomposition using Loess (Cleveland et al., 1990).

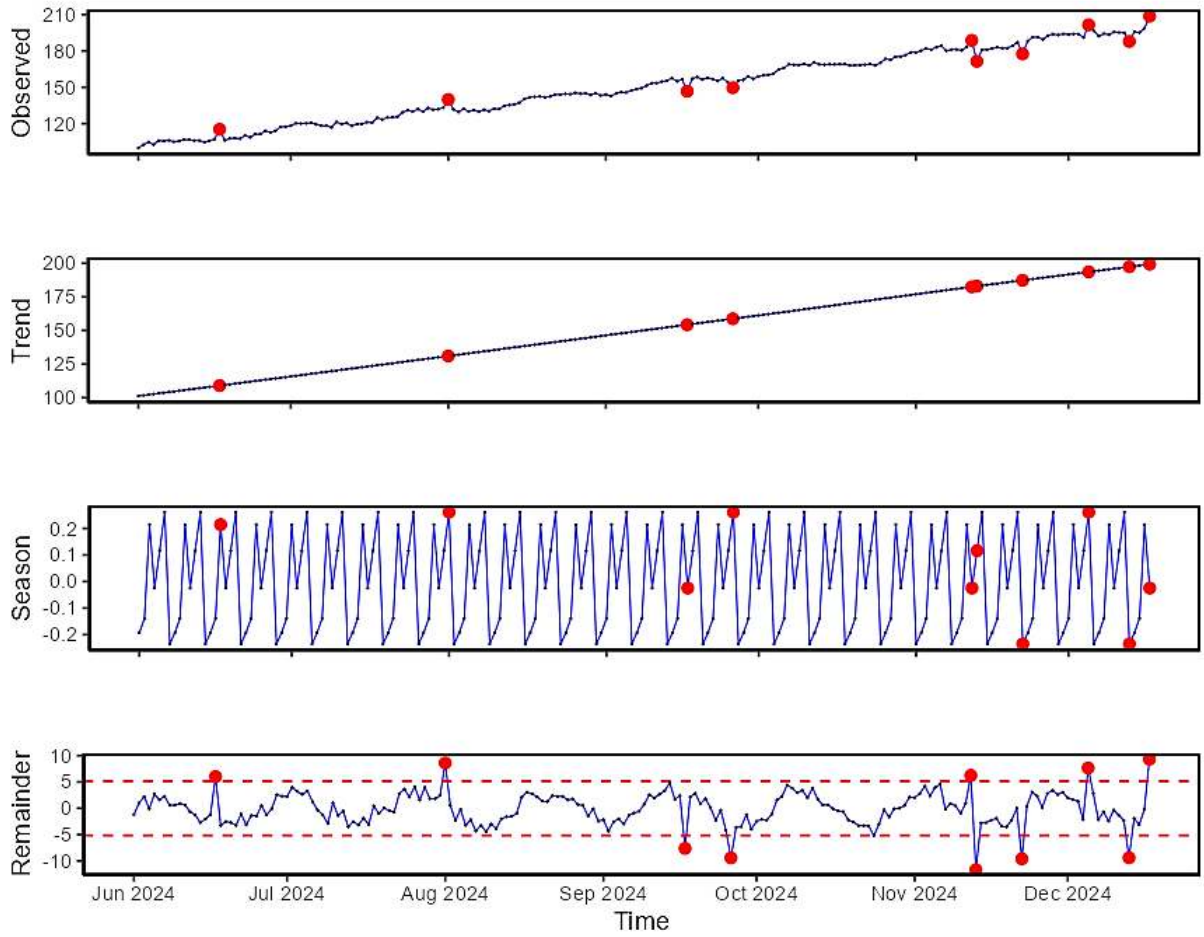

Figure 1. Presentation of identified anomalies (red points) on the decomposition plot of the time series. Source: own elaboration.

Figure 1 illustrates the additive decomposition of a time series into four main components: Observed, Trend, Season, and Remainder (Observed = Trend + Season + Remainder). Each plot highlights the analyzed series with a blue line, with anomalies marked as red points. The Remainder component represents the residual values, which are not explained by the systematic patterns of the series: trend and seasonality. The fundamental idea behind anomaly detection is to analyze the Remainder component based on statistical criteria. The basis lies in the variability of the series and deviations from the average error level. Outlier detection methods are most commonly used, with the anomaly region located outside the range defined by the dashed lines on the Remainder plot.

Outliers are identified based on various distance-based criteria, with the most commonly used methods including:

- basic statistical methods, such as boxplot-based approaches (IQR test), standard deviation thresholds, and statistical tests (e.g., Grubbs' test, Dixon's test),
- quantitative methods: a fixed number (or fraction) of the most deviating values,

- clustering-based criteria: deviations are identified as clusters (groups) with the smallest sizes, utilizing unsupervised learning mechanisms,
- machine learning-based criteria: approaches leveraging various supervised learning algorithms.

Although various metrics are used for anomaly detection, relatively few studies focus directly on a multi-criteria approach. Two studies indexed in the Scopus database explicitly refer to anomaly detection and a multi-criteria approach in their titles (Hsiao et al., 2015; Zafari et al., 2022). In Zafari et al. (2022), different anomaly metrics are evaluated to establish a final threshold defining anomalies. This study focuses on detecting irregularities in the circulation of prescriptions in the pharmaceutical market and identifying potential fraud. The final assessment is based on three measures related to the Gini index and drug (Opioid) scoring. The study by Hsiao et al. (2015) presents an anomaly detection method based on multi-criteria similarity measures and introduces a new metric – Pareto depth. This study proposes the Pareto Depth Analysis (PDA) method for anomaly identification.

In other bibliographic databases, relatively few studies reference a multi-criteria approach to anomaly detection. Ribeiro et al. (2020) proposed a multi-criteria approach to detect anomalies in drinking water quality, aiming to balance false alarms and missed detections during anomaly occurrences. Multi-criteria methods were also employed to evaluate machine learning algorithms for network access classification in the context of anomaly detection (Nascimento, Santos, 2022). Similarly, Wu et al. (2021) presented a multi-criteria approach to identifying anomalies in the energy systems of the iron and steel industry. Additionally, Dauwe et al. (2014) utilized a multi-criteria quality assessment model for noise monitoring networks to automatically detect anomalies in measurement data.

The purpose of this study is to present and propose a multi-criteria approach, along with the aggregation of these criteria, to provide a quantified assessment of observations that are potential anomalies.

2. Methods

2.1. Incorporating Multiple Criteria in Anomaly Detection

The proposed approach incorporates multiple criteria (methods, techniques) for anomaly detection. A method for aggregating anomaly detection results is introduced in three variations:

1. restrictive aggregation (restrictive aggregation) – an anomaly is defined as a value identified by all the considered criteria,
2. liberal aggregation (liberal detection) – an anomaly is defined as a value identified by any of the considered criteria,

3. aggregation by summing criteria indicating anomalies (scoring-based aggregation) – a potential anomaly is assigned a score based on the number of criteria under which the observation in the series is classified as an anomaly.

The framework of the proposed approach is illustrated in Figure 2.

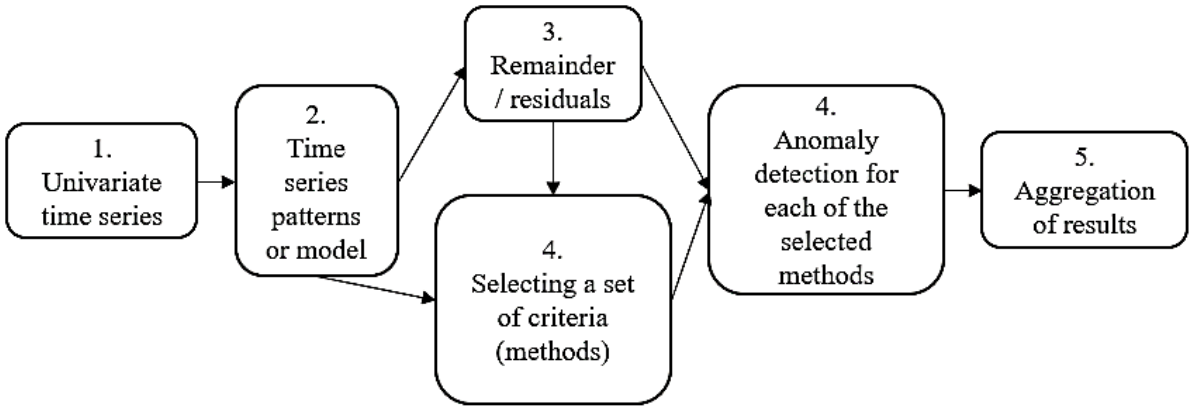

Figure 2. Process diagram of anomaly detection in univariate time series using multiple criteria.
Source: own elaboration.

Figure 2 illustrates the process diagram for anomaly detection in univariate time series. The process begins with the analysis of the time series (1) and the identification of patterns or the development of a time series model (2). Subsequently, after removing the identified patterns, the residual component (3) is obtained and analyzed for anomalies. For this purpose, a set of criteria (4) is selected, enabling anomaly detection for each chosen approach. Finally, the analysis results are aggregated (5) to provide a final assessment of the anomalies.

The fundamental premise of the proposed approach is the identification of anomalies within a fixed time window, represented by the entire analyzed time series. Consequently, this process can be implemented in more complex anomaly detection systems.

A more detailed description of the proposed analysis is presented using a numerical example.

2.2. Detailed description of the proposed approach using a numerical example

2.2.1. Generating Test Data for Anomaly Detection in Time Series

To demonstrate the proposed approach for anomaly detection, a time series was generated as an example for testing anomaly detection algorithms. This series combines characteristics of real-world data (trend, seasonality, noise) with controlled deviations, enabling the evaluation of method effectiveness in a controlled environment.

First, a linear trend was defined, introducing a systematic increase in values over time. White noise and random changes from a uniform distribution were added to simulate natural variability. Next, a periodic component was introduced to incorporate cyclical patterns. Subsequently, ten time points from the series were randomly selected and modified by adding or subtracting anomaly values calculated as a multiple of the original series values.

This modification aimed to simulate deviations from the pattern, representing anomalies in the data. The simulated time series, along with the generated deviations from the original series, is shown in Figure 3.

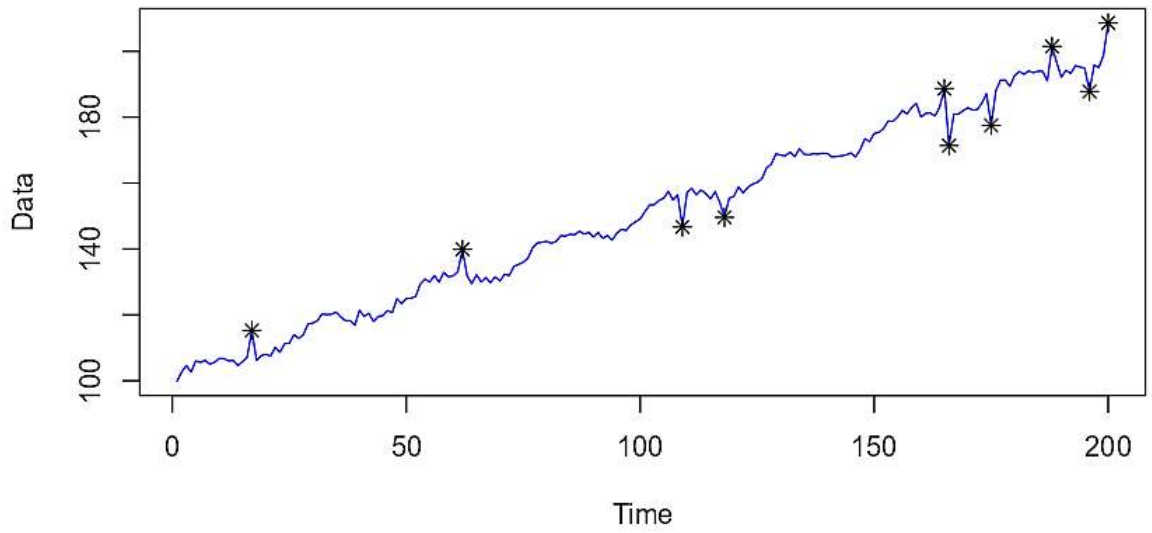

Figure 3. Visualization of a time series with marked deviations from the pattern.

Source: own elaboration.

2.2.2. Selected Methods for Time Series Modeling and Anomaly Detection

Eight methods were selected for anomaly detection, combining time series modeling with anomaly identification techniques. Time series representation utilized STL decomposition and the ARIMA model with automatic parameter selection (Hyndman, Khandakar, 2008; Wang et al., 2006). Anomaly detection on the residual component employed the following approaches:

- three-sigma rule (anomaly defined as deviations beyond 3 standard deviations): an anomaly is defined as a residual value deviating by more than three standard deviations,
- boxplot rule: an anomaly is a value that lies outside the whiskers of a classic boxplot, where whiskers extend up to 1.5 times the interquartile range,
- hierarchical clustering into four clusters: anomalies are values belonging to the two clusters with the smallest proportion of total observations (it is assumed that one cluster represents extremely negative values, the other represents extremely positive values, while the remaining two clusters contain typical values).
- K-means clustering into four clusters: similar to hierarchical clustering, anomalies are values belonging to the two clusters with the smallest proportion of total observations.

Based on this, the selected methods can be specifically defined as criteria for anomaly identification:

- Method 1: time series modeled with ARIMA, anomalies identified as observations deviating from the mean residuals by more than three standard deviations.
- Method 2: time series modeled with ARIMA, anomalies identified as outliers based on a classic boxplot.
- Method 3: time series modeled with ARIMA, anomalies identified as observations extracted using hierarchical clustering.
- Method 4: time series modeled with ARIMA, anomalies identified as observations extracted using k-means clustering.
- Method 5: time series decomposed using STL, anomalies identified as observations deviating from the mean residuals by more than three standard deviations.
- Method 6: time series decomposed using STL, anomalies identified as outliers based on a classic boxplot.
- Method 7: time series decomposed using STL, anomalies identified as observations extracted using hierarchical clustering.
- Method 8: time series decomposed using STL, anomalies identified as observations extracted using k-means clustering.

A common feature of the methods is that they are independent of the assumed significance level and do not account for the maximum or minimum number of identified anomalies.

The relationships between time series models and anomaly identification methods applied to the residual component are presented in Figure 4.

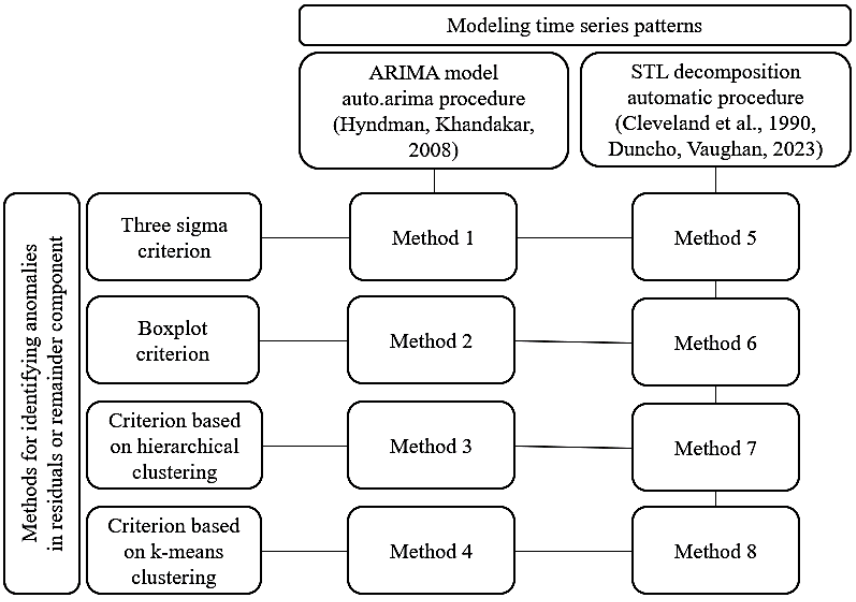

Figure 4. Approach for anomaly detection in time series – combining modeling and identification methods.

Source: own elaboration.

2.2.3. Aggregation of results

The aggregation of results is based on the application of three approaches:

- Restrictive approach: a value in the series is considered an anomaly only if it is identified by all the considered methods (criteria).
- Liberal approach: a value in the series is considered an anomaly if it is identified by at least one method.
- Scoring approach: for each value in the series identified as an anomaly, the number of methods (criteria) recognizing it as an anomaly is summed.

The restrictive approach results in the smallest set of values classified as anomalies, while the liberal approach produces the largest set. The scoring approach provides a quantified evaluation of values deviating from the pattern, which can serve as a foundation for further studies and analyses.

Ultimately, the time series receives a scoring evaluation of potential anomalies alongside the extreme approaches to anomaly detection.

3. Results

The results of anomaly identification for each method are presented in Figures 5-12.

In each figure, the blue line represents the time series under analysis, while the red line shows the predicted (fitted) values. Artificially generated deviations are marked with asterisks, and anomalies identified by the methods are depicted as red filled circles.

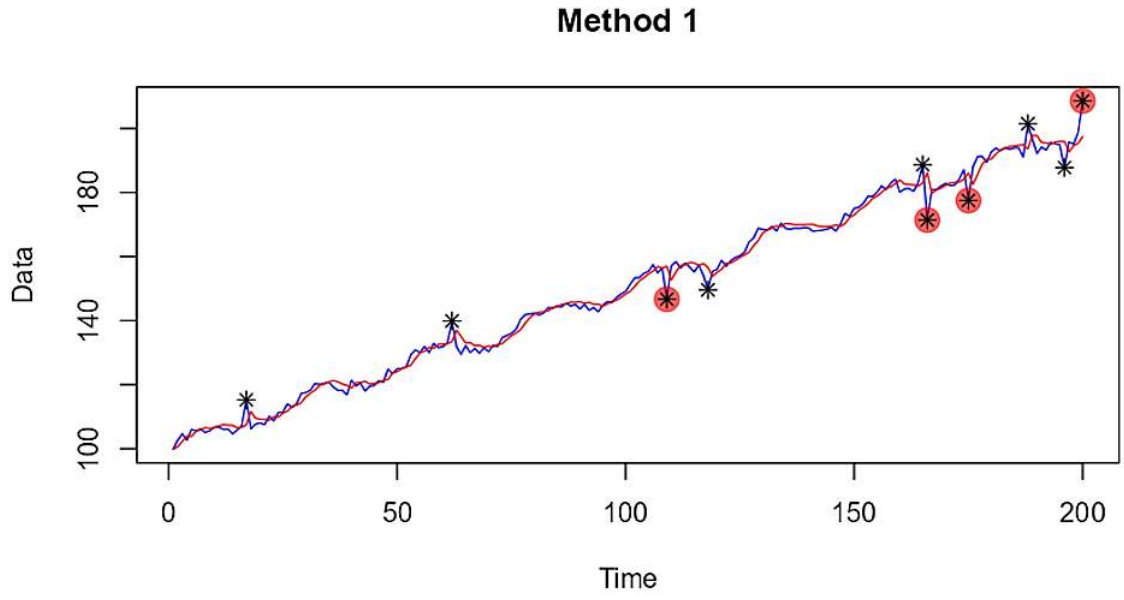

Figure 5. Presentation of identified anomalies using method 1 (ARIMA model with 3-sigma rule). Source: own elaboration.

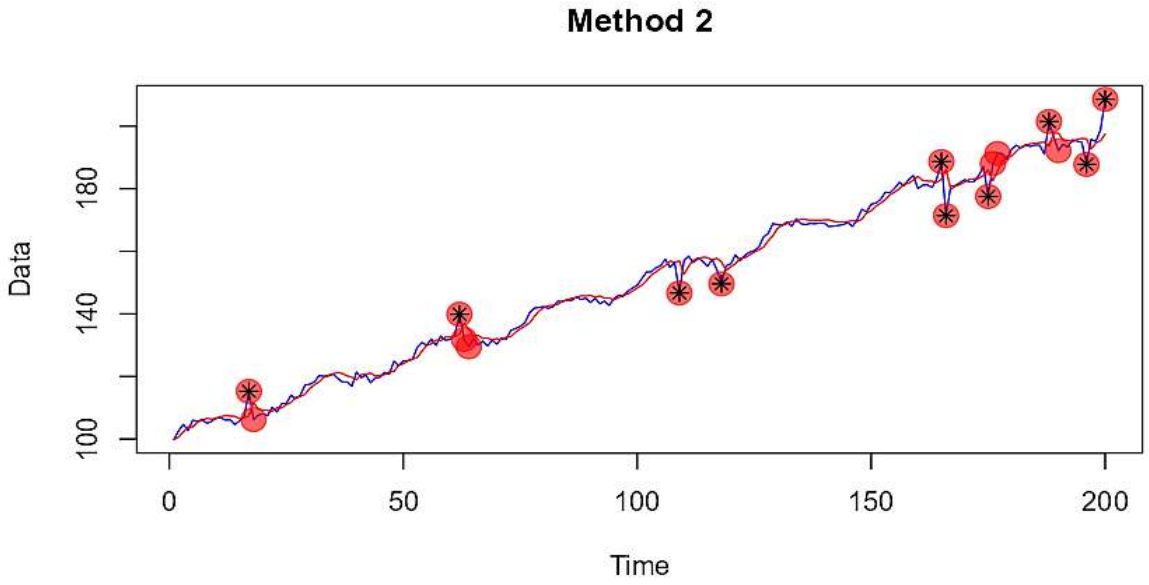

Figure 6. Presentation of identified anomalies using method 2 (ARIMA model with boxplot rule).

Source: own elaboration.

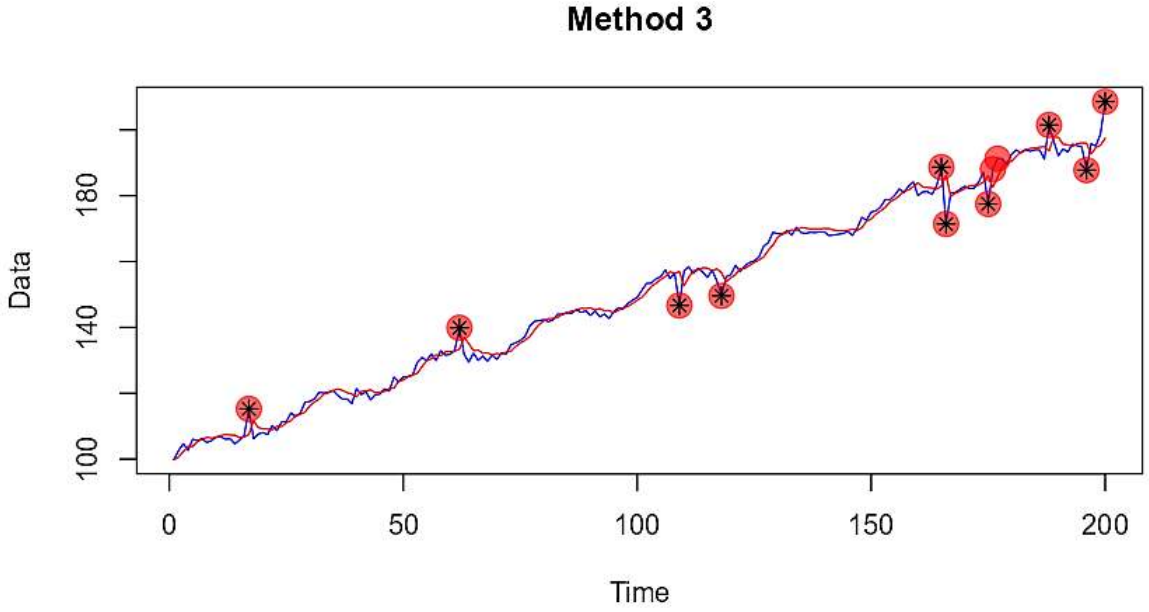

Figure 7. Presentation of identified anomalies using method 3 (ARIMA model with hierarchical clustering rule).

Source: own elaboration.

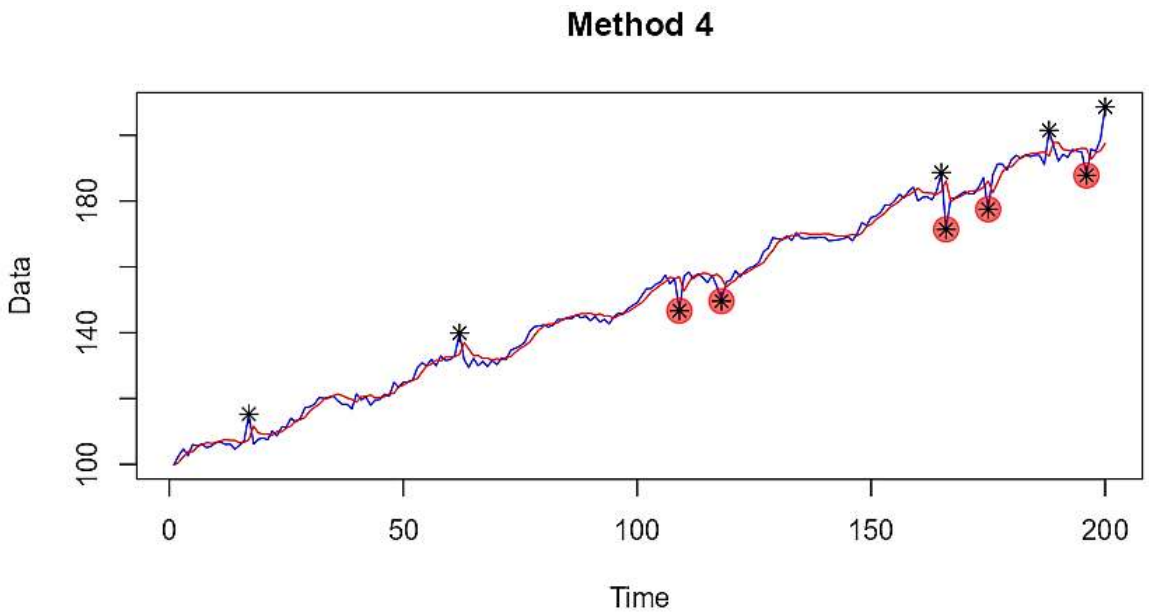

Figure 8. Presentation of identified anomalies using method 4 (ARIMA model with k-means clustering rule).

Source: own elaboration.

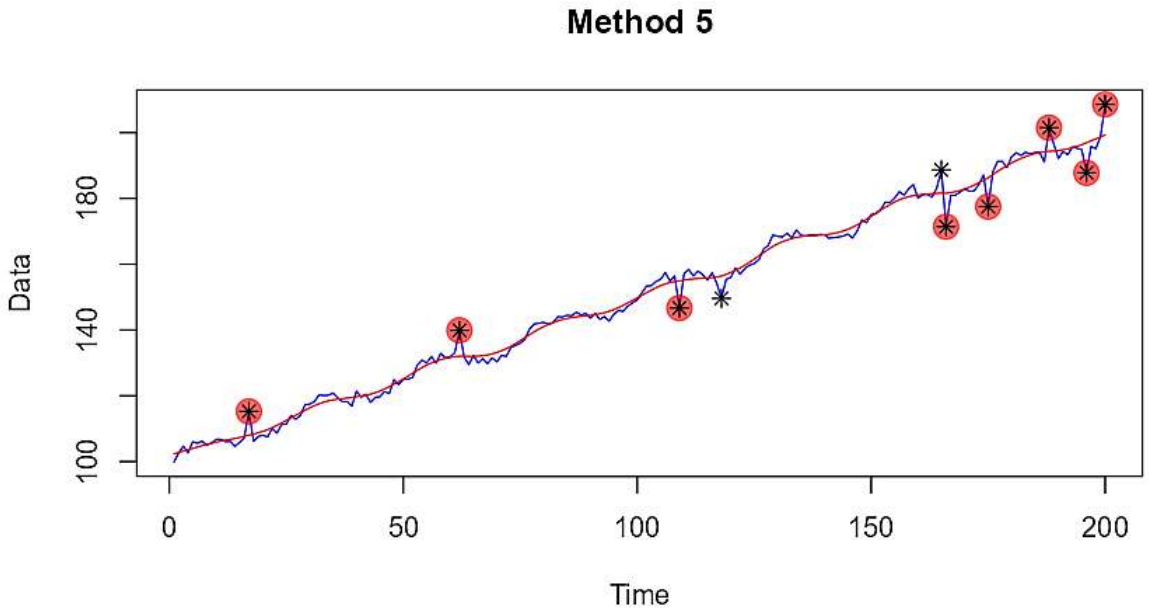

Figure 9. Presentation of identified anomalies using method 5 (STL model with 3-sigma rule).

Source: own elaboration.

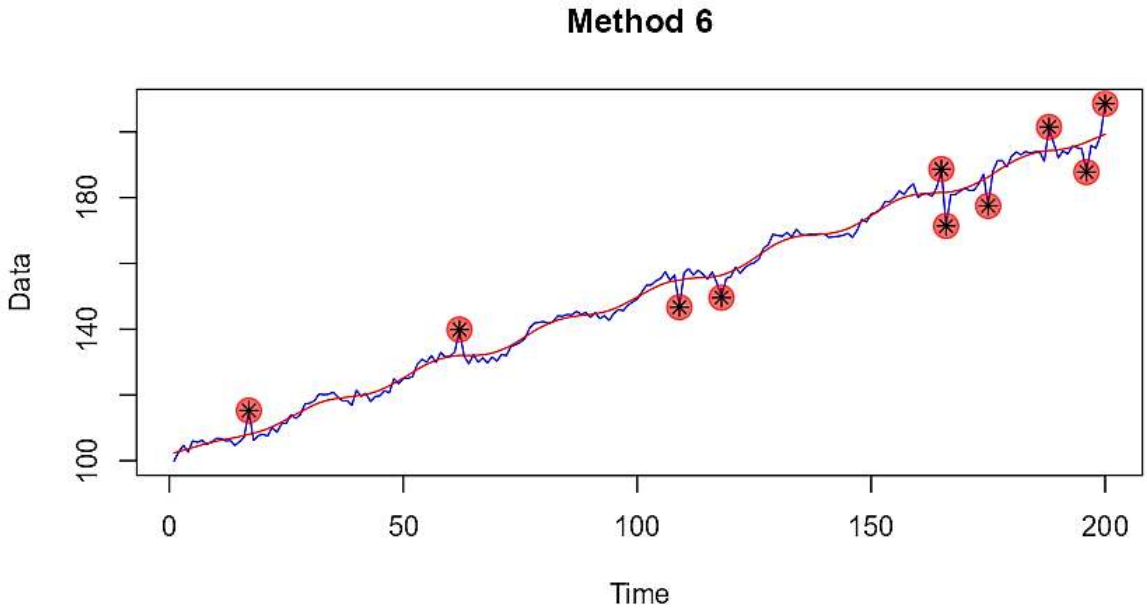

Figure 10. Presentation of identified anomalies using method 6 (STL model with boxplot rule).

Source: own elaboration.

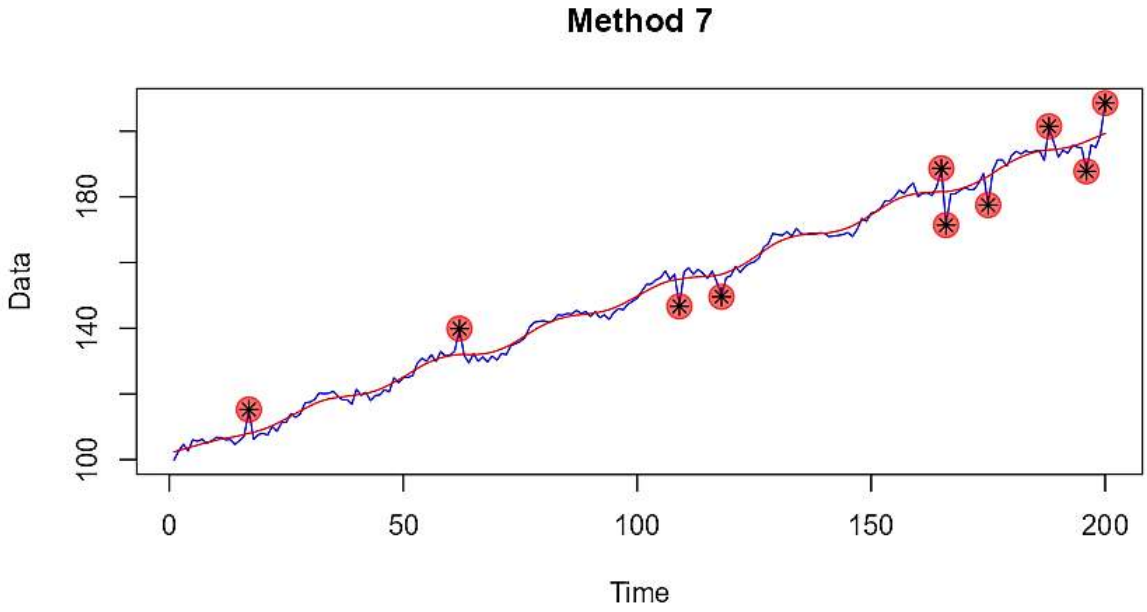

Figure 11. Presentation of identified anomalies using method 7 (STL model with hierarchical clustering rule).

Source: own elaboration.

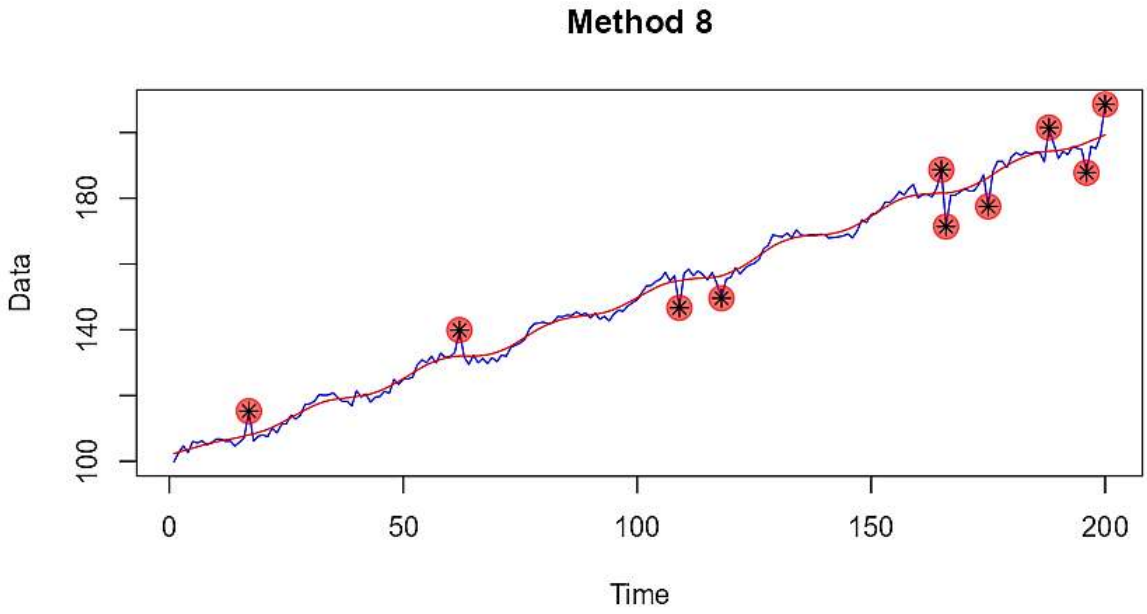

Figure 12. Presentation of identified anomalies using method 8 (STL model with k-means clustering rule).

Source: own elaboration.

The results of aggregated anomaly detection using the restrictive approach are presented in Figure 13. Figure 14 shows the results for the liberal approach, while Figure 15 illustrates the scoring approach.

Additionally, in Figure 15, each identified point is annotated with the number of methods by which that point was classified as an anomaly. The size of the circles reflects this number, meaning the larger the circle, the stronger the justification for classifying the observation as an anomaly.

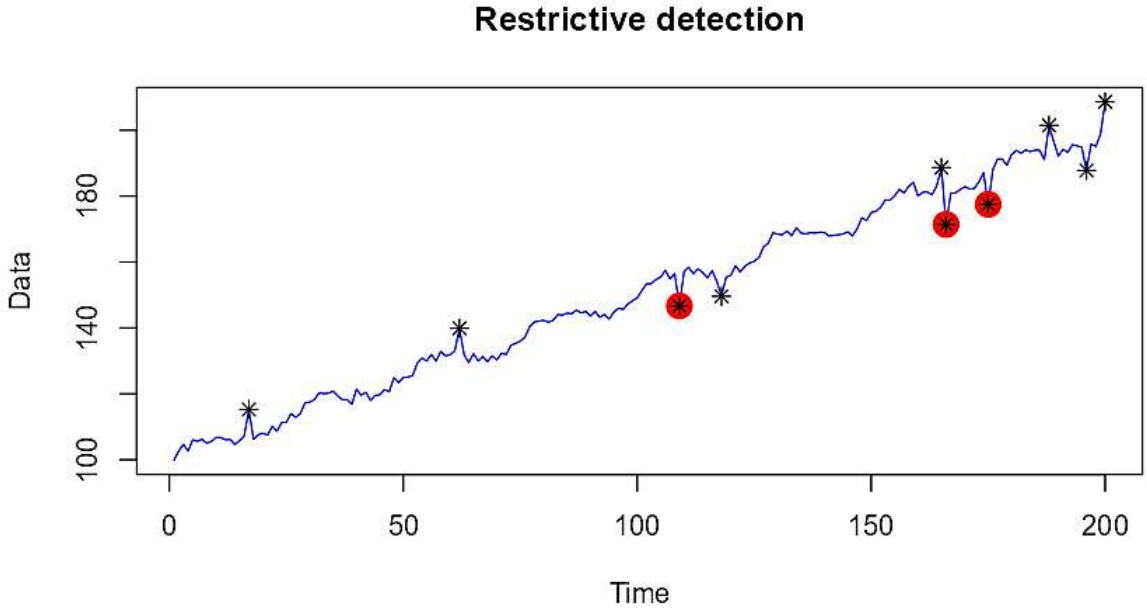

Figure 13. Identification of anomalies using the restrictive approach.

Source: own elaboration.

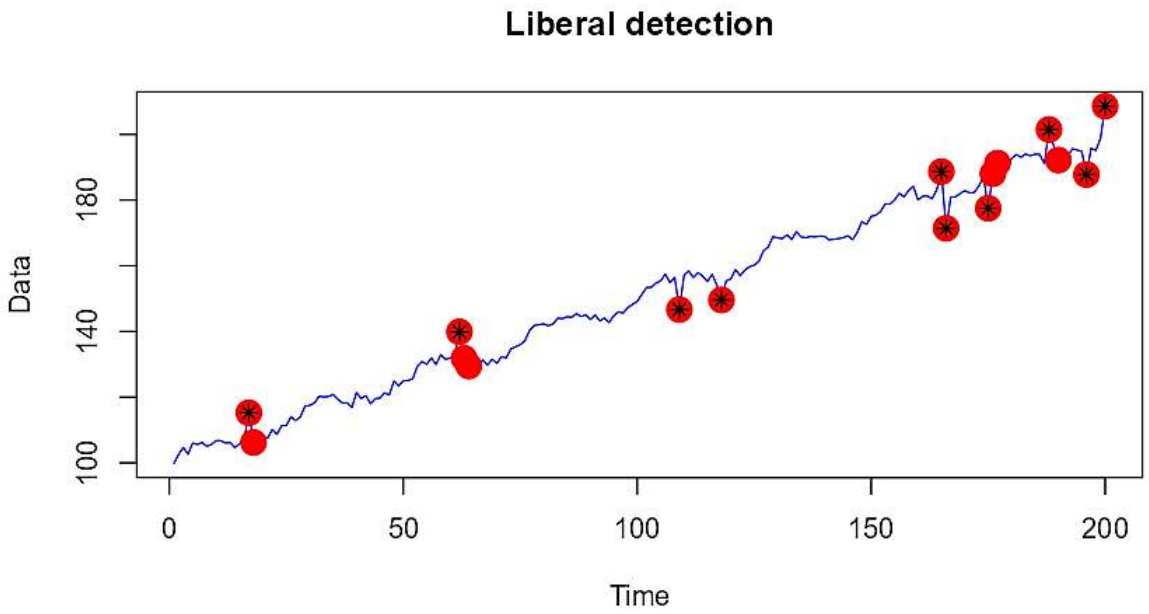

Figure 14. Identification of anomalies using the liberal approach.

Source: own elaboration.

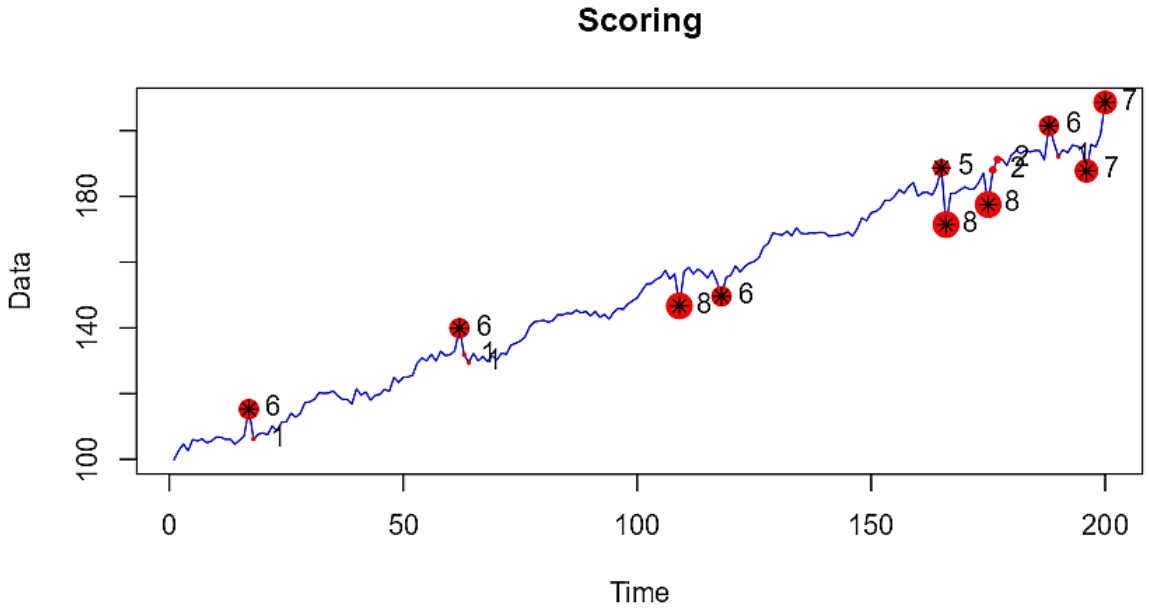

Figure 15. Identification of anomalies using the scoring approach.

Source: own elaboration.

Using the restrictive approach, only three observation was identified as an anomaly. The liberal approach resulted in the largest number of observations classified as anomalies. The scoring approach provided a quantified assessment of the identified anomalies.

4. Discussion

The presented results highlight key differences among various anomaly detection methods. The applied approaches (restrictive, liberal, and scoring-based) offer diverse strategies for detecting deviations, each suitable for specific problem contexts.

The restrictive approach ensures high specificity, reducing false alarms, but at the potential cost of missing significant anomalies. This makes it advantageous in scenarios where minimizing false positives is critical, such as in safety-critical systems. In contrast, the liberal approach, while more inclusive, may generate an excess of false positives, limiting its applicability for analyzing large datasets where precision is paramount. The scoring approach provides a balanced compromise, quantifying the significance of observed deviations, which can be valuable in decision-making processes.

It is worth noting that the results vary depending on the modeling method used (ARIMA, STL decomposition) and the anomaly detection criteria. The agreement observed in the outcomes of Methods 7 and 8 suggests they may be more universally applicable in the studied context, though further research is necessary.

One limitation of this study is the lack of evaluation of the methods' effectiveness in real-world applications, representing an important area for future research. A next step could involve a comparative analysis of the proposed approach’s efficiency across various domains, such as industry or finance.

Another crucial aspect is that time series anomaly detection frequently involves sliding time windows and artificial intelligence methods (Kao, Jiang, 2019; Lu et al., 2023). Future research could incorporate the proposed methodology into analyses based on sliding time windows. Expanding the set of methods may also enhance the precision of quantifying anomalies in time series.

The proposed approach may also prove useful for examining forecasting error series, which can exhibit certain patterns, where patterns and significant deviations from them might be classified as anomalies (Wolny, 2023).

5. Summary

This paper explores anomaly detection in time series through a multi-criteria approach, addressing the increasing complexity and volume of data in modern applications. Anomaly detection plays a vital role across various domains, such as industry, finance, healthcare, and cybersecurity, by identifying critical deviations that may indicate potential risks or opportunities. The study focuses on integrating multiple criteria to enhance anomaly detection precision, utilizing both statistical and machine learning techniques.

The proposed methodology includes three aggregation strategies for anomaly identification: restrictive, liberal, and scoring-based approaches. These strategies balance specificity and sensitivity, catering to diverse application requirements. The restrictive approach emphasizes minimizing false positives, while the liberal approach prioritizes inclusivity. The scoring method provides a quantifiable assessment of potential anomalies, combining insights from multiple detection criteria.

The results demonstrate significant differences between detection methods, with models based on ARIMA and STL decomposition exhibiting varied performance. A comparative analysis of methods highlights the potential universality of some approaches, such as those involving clustering algorithms. However, further research is required to validate these findings across real-world datasets and dynamic applications, including sliding time windows and advanced artificial intelligence techniques.

In conclusion, the study underscores the importance of adopting a multi-criteria perspective in anomaly detection to achieve more robust, adaptable, and precise solutions. Future work should extend the proposed framework to include additional criteria and dynamic contexts, enhancing its applicability and reliability in practical scenarios.

References

1. Box, G.E., Jenkins, G.M., Reinsel, G.C., Ljung, G.M. (2015). *Time series analysis: forecasting and control*. John Wiley & Sons.
2. Braei, M., Wagner, S. (2020). Anomaly detection in univariate time-series: A survey on the state-of-the-art. *arXiv preprint arXiv:2004.00433*.
3. Chandola, V., Banerjee, A., Kumar, V. (2009). Anomaly detection: A survey. *ACM computing surveys (CSUR)*, *41(3)*, pp. 1-58.
4. Cleveland, R.B., Cleveland, W.S., McRae, J.E., Terpenning, I. (1990). STL: A seasonal-trend decomposition. *J. off. Stat*, *6(1)*, pp. 3-73.
5. Dancho, M., Vaughan, D. (2023). Anomalize: Tidy anomaly detection. *R package version 0.3.0*. Retrieved from: https://CRAN.R-project.org/package=anomalize.
6. Dauwe, S., Oldoni, D., De Baets, B., Van Renterghem, T., Botteldooren, D., Dhoedt, B. (2014). Multi-criteria anomaly detection in urban noise sensor networks. *Environmental Science: Processes & Impacts*, *16(10)*, pp. 2249-2258.
7. Hsiao, K.J., Xu, K.S., Calder, J., Hero, A.O. (2015). Multicriteria similarity-based anomaly detection using Pareto depth analysis. *IEEE transactions on neural networks and learning systems*, *27(6)*, pp. 1307-1321.
8. Hyndman, R.J., Khandakar, Y. (2008). Automatic time series forecasting: the forecast package for R. *Journal of statistical software*, *27*, pp. 1-22.

9. Kao, J.B., and Jiang, J.R. (2019). Anomaly detection for univariate time series with statistics and deep learning. *IEEE Eurasia conference on IOT, communication and engineering (ECICE, October 2019),* pp. 404-407.
10. Lu, T., Wang, L., Zhao, X. (2023). Review of anomaly detection algorithms for data streams. *Applied Sciences*, *13(10), 6353*.
11. Mehrotra, K.G., Mohan, C.K., Huang, H. (2017). *Anomaly Detection Principles and Algorithms. Terrorism, Security, and Computation.* Springer International Publishing, doi:10.1007/978-3-319-67526-8
12. Mills, T.C. (2019). *Applied time series analysis: A practical guide to modeling and forecasting.* Academic press. Berlin: Springer.
13. Nascimento, G.B. Santos, M. (2022). Performance evaluation of machine learning algorithms for network anomaly detection: an approach through the AHP-TOPSIS-2N method. *Procedia Computer Science, 214*, pp. 164-171.
14. Nielsen, A. (2019). *Practical time series analysis: Prediction with statistics and machine learning*. O'Reilly Media.
15. Ribeiro, V.H.A., Moritz, S., Rehbach, F., Reynoso-Meza, G. (2020). A novel dynamic multi-criteria ensemble selection mechanism applied to drinking water quality anomaly detection. *Science of The Total Environment, 749, 142368*.
16. Wang, X., Smith, K., Hyndman, R. (2006). Characteristic-based clustering for time series data. *Data mining and knowledge Discovery*, *13, 335-364*.
17. Wolny, M. (2023). A Decomposition Study of the Time Series of Electricity Consumption Forecasting Errors. *Zeszyty Naukowe Organizacja i Zarządzanie, 171.* Politechnika Śląska, pp. 173-182.
18. Wu, H., Jin, F., Zhao, J., Wang, W. (2021). Anomaly detection method based on multi-criteria evaluation for energy data of steel industry. *IEEE 10th Data Driven Control and Learning Systems Conference (DDCLS)*, pp. 741-747.
19. Zafari, B., Ekin, T., Ruggeri, F. (2022). Multicriteria decision frontiers for prescription anomaly detection over time. *Journal of Applied Statistics, 49(14)*, pp. 3638-3658.

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INVESTMENT RISK ASSESSMENT IN THE RAW MATERIALS MARKET IN THE ERA OF CHANGES

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Purpose: Dynamic changes taking place in investment markets, related to the negative effects of the COVID-19 pandemic and armed conflicts in the world, have led to an intensification of research related to the search for effective risk management methods. In the case of the raw materials market, investment risk is often identified with the volatility of their prices. One of the alternative measures of volatility, and therefore risk, is the fractal dimension. The aim of the research will be to assess investment risk in the raw materials market using the fractal dimension.
Design/methodology/approach: Investment risk assessment was performed based on value at risk and a non-classical risk measure, which is the fractal dimension. Rescaled range analysis based on the Hurst exponent was used to estimate this dimension.
Findings: The paper attempts to assess investment risk in the raw materials market using a non-classical method, which is the fractal dimension. It has been shown that raw materials, especially metals, can be a significant source of capital multiplication in the event of economic and financial crises, because they are characterized by lower risk.
Research limitations/implications: The use of different methods for estimating the fractal dimension gives similar but different results. Any discrepancies do not result only from possible imperfections of the methods used, but are the effect of applying them to series of finite length, i.e. only for a sufficiently large number of observations will the values of the fractal dimension approach theoretical levels.
Practical implications: The modern investment market is very competitive, therefore risk analysis and assessment is extremely important for every investor.
Originality/value: Study of the influence of anomalies (crisis phenomena) on the value of the fractal dimension.
Keywords: Investment risk, raw materials market, fractal dimension, rescaled range analysis.
Category of the paper: Research paper.

1. Introduction

From an investment perspective, the raw materials market is an interesting alternative to investing in the capital market, especially during periods of economic crisis. An example is the above-average increase in the price of gold in mid-2008, which coincided with huge declines in the financial markets. Therefore, the dynamic changes currently taking place on the capital market, related to the negative effects of the Covid-19 pandemic and the war in Ukraine, have increased interest in investments that will diversify the portfolio and led to an intensification of studies on the search for effective risk management methods (Drozd, 2020; Krężołek, 2020).

In the case of raw materials, investment risk is often identified with the volatility of their prices. One of the alternative measures of volatility, and therefore risk, is the fractal dimension. It determines the degree of jaggedness of the time series graph, which allows us to assume that the larger the dimension of the series, the greater its volatility. In this case, financial instruments whose return rate series have a larger dimension are more volatile, which means that they are more risky.

The fractal dimension was created as a measure of geometric objects. However, the scope of applications has naturally expanded, including the description of time series. Currently, this dimension is used in medicine (Beckers et al., 2006; Sobolewska-Siemieniuk et al., 2007; Lawrence et al., 2015), in urban planning (Chen, 2013; Wang, 2017; Jahanmiri, Parker, 2022), or economics and finance (Mandelbrot, 2010; Orzeszko, 2010; Sanchez-Granero et al., 2012; Andronache et al., 2016). The methodology for estimating the fractal dimension is also being developed (Zwolankowska, 2000; Sy-Sang, Feng-Yuan, 2009, Przekota, 2003). In Polish literature on the subject, much attention was devoted to the fractal dimension by Buła (2017), Zeug-Żebro (2020), Przekota (2022).

The aim of the article was to examine investment risk during the changes observed in the contemporary world and to apply the fractal dimension to assess the volatility of return rates of selected commodities. The study was conducted based on value at risk and a non-classical risk measure, which is the fractal dimension. Rescaled range analysis was used to estimate this dimension. The study used time series created from the closing prices of futures contracts for commodities: aluminum, natural gas, crude oil and gold. The data covered the period from 01.01.2018 to 31.10.2023.

2. Changes in raw material prices in the face of the challenge s of the modern world

Raw materials are the subject of numerous market transactions. They play a major role in various investment strategies, and are also widely used in industry. Their prices are fundamentally influenced by the relationship between supply and demand (in relation to their use), on the one hand, and by the investment demand for these assets, on the other. The beginning of the 21st century brought significant changes to the raw materials market. Investors have begun to treat them as alternative and safe investment assets. As a result, raw materials (derivatives) are increasingly used to diversify investment portfolios.

Commodity prices are also largely dependent on economic, political and climatic events around the world. Floods, droughts, armed conflicts or recessions can cause significant fluctuations in the price of these assets. Good examples include the coronavirus pandemic (the rise in gold prices and the fall in aluminum, natural gas and oil prices) and the war in Ukraine and the pressure it has caused on the commodity and energy markets.

Price changes in the raw materials market are usually long-term. They could be observed in the case of the raw materials already mentioned in the article (aluminum, crude oil and natural gas). Their stock prices increased significantly between 2021 and 2022 along with the economic recovery after the coronavirus pandemic (Figure 1).

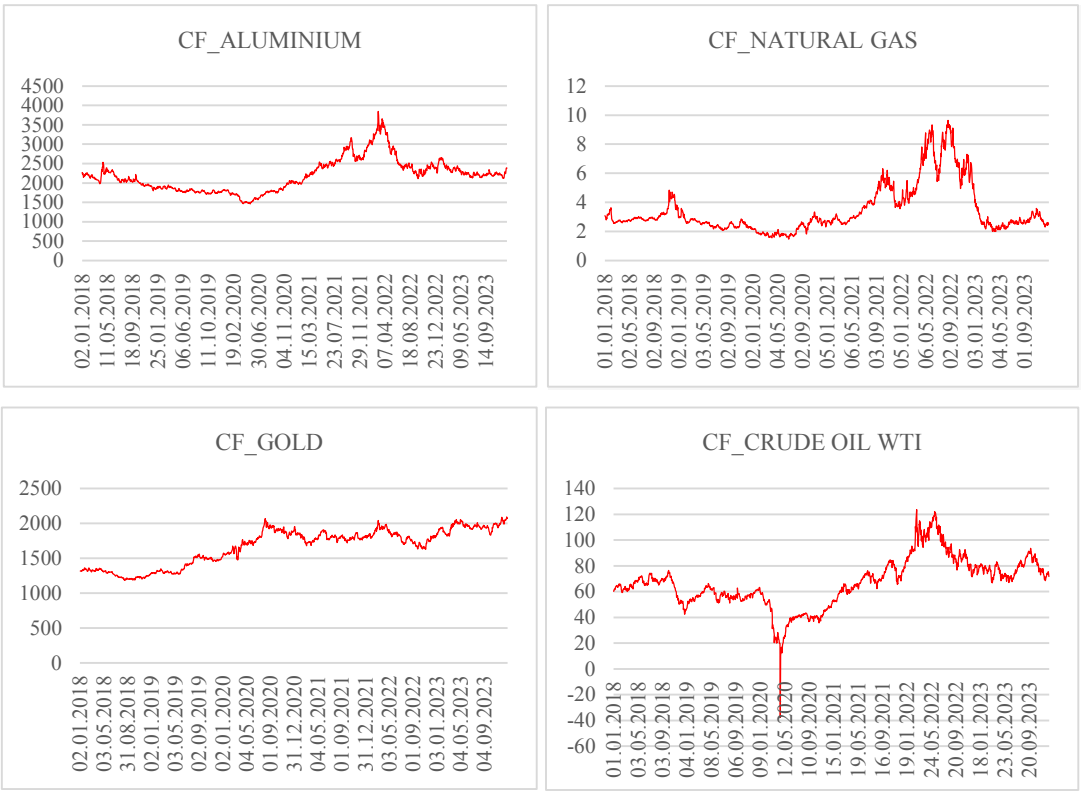

Figure 1. Price quotations for contracts for aluminum, gold, natural gas and WTI oil in the period from 1 January 2018 to 31 December 2023.

Source: own study based on stooq.pl.

In 2018-2019, the average futures prices for aluminum, crude oil, natural gas and gold were quite stable. The values of the coefficients of variation for this period were low (Table 1).

The outbreak of the COVID-19 pandemic and the restrictions introduced in many countries led to a collapse in global demand for many goods. In the first months of the crisis, significant declines in quotations could be observed among the analyzed commodities. Taking into account the entire period of 2020-2021, a decrease in the average price could be observed only for crude oil ($53.72/bbl). Other commodities recorded an increase, with the highest quotations being achieved by gold contracts ($1789.09/ozt). In 2020-2021, the calculated coefficient of variation was at the level of: 0.33 for crude oil and 0.38 for natural gas (increasing three times compared to the previous sub-period of analysis). The lowest value of this indicator of 0.06 could be observed for gold.

Table 1.
Characteristics of price volatility of futures contracts for selected raw materials in 2018-2023

Descriptive statistics	Crude oil WTI	Aluminium	Natural gas	Gold
	2018-2019			
Average price	60.98	1961.43	2.80	1334.43
Minimum price	42.53	1705.00	2.07	1184.00
Maximum price,	76.41	2537.00	4.84	1560.40
Standard deviation	6.68	181.93	0.48	99.43
Coefficient of variation	0.11	0.09	0.17	0.07
	2020-2021			
Average price	53.72	2108.53	2.93	1789.09
Minimum price	-37.63	1462.00	1.48	1477.90
Maximum price,	84.65	3171.50	6.31	2069.40
Standard deviation	17.48	443.21	1.13	106.24
Coefficient of variation	0.33	0.21	0.38	0.06
	2022-2023			
Average price	86.03	2501.46	4.60	1880.25
Minimum price	66.74	2114.00	1.99	1630.90
Maximum price,	123.70	3849.00	9.65	2093.10
Standard deviation	12.85	381.84	2.24	107.21
Coefficient of variation	0.15	0.15	0.49	0.06

Source: own study.

In the first months of 2022, as tensions on the Russian-Ukrainian border intensified, the prices of all the analyzed raw materials began to rise. In the second quarter of this year, the maximum prices of these raw materials reached very high levels: crude oil $123.70/bbl, aluminum $3849/t, natural gas $9.65/mmBtu and gold $1880.25/ozt. Despite some declines in the prices of these raw materials at the end of the third quarter of 2022, their prices remained at very high levels. The persistence of such high prices of crude oil or cold gas had a negative impact on global economic growth and caused an increase in inflation in many countries. In 2023, the prices of the raw materials under consideration (except gold) began to decline and returned to a similar level from before the pandemic. The coefficients of variation in the period 2022-2023 for crude oil, aluminum and gold took low values (≤ 0.15). The exception was the result obtained for natural gas equal to 0.49, for which high volatility of quotations can be observed.

3. Selected risk measures

The fractal dimension is one of the characteristics of chaotic systems and is used to describe structurally complex geometric objects, e.g. time series. This dimension examines the extent to which the analyzed object (series) fills the space in which it is embedding (Orzeszko, 2010). Its characteristic feature is the fact that it can take non-integer values, e.g. a curve on a plane has a dimension from the interval [1, 2].

The relationship between the variability of a series and its fractal dimension can be easily observed on a graph. Series characterized by greater variability have more jagged graphs, and consequently a larger dimension. This relationship is clearly illustrated in Figure 2. It shows three graphs of the Weierstrass-Mandelbrot function for different values of the fractal dimension.

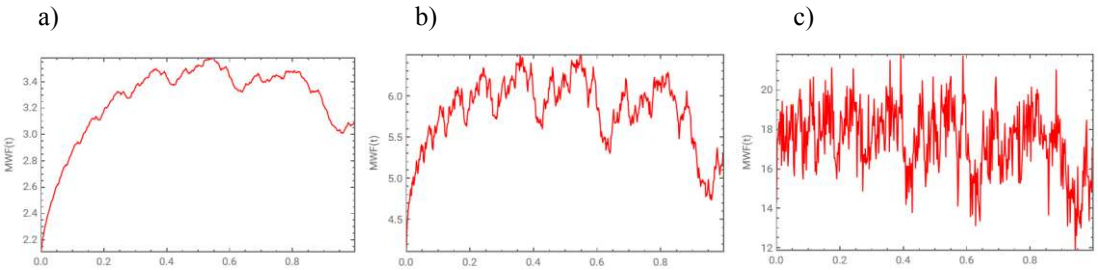

Figure 2. Weierstrass-Mandelbrot function for different values of fractal dimension: a) $D(A) = 1.1$, b) $D(A) = 1.5$, c) $D(A) = 1.9$.

Source: own study.

It has been proven that the graphs of the Weierstrass-Mandelbrot function are fractals (Dubuc et al., 1989).

In the case of fast-changing series (anti-persistent, $D(A) > 1.5$), the higher the fractal dimension, the more often a trend reversal can be observed. In turn, for slow-changing series (persistent, $D(A) < 1.5$)), the lower the value of this dimension, the stronger the trend strengthening phenomenon. For this reason, the fractal dimension has been recognized as an important characteristic of time series from the financial market, allowing for the assessment of investment risk (Buła, 2012).

The fractal dimension of a given geometric object A can be calculated by estimating the minimum number of closed hypercubes with side length ε needed to cover it. This dimension is determined based on the following formula:

$$D(A) = \lim_{\varepsilon \to \infty} \frac{\ln L(A,\varepsilon)}{\ln\left(\frac{1}{\varepsilon}\right)}, \tag{1}$$

where $L(A, \varepsilon)$ is the minimum number of hypercubes with side length ε.

A significant problem related to the study of financial time series in the fractal approach is the fact that their graphical representations should be classified as natural stochastic fractals. Due to the impossibility of a priori determining the laws governing the fluctuations of the quantities studied, it is also impossible to calculate the fractal dimension and it is necessary to use appropriate estimation methods:

- segmental-variational method (Zwolankowska, 2000),
- field division method (Przekota, 2003),
- rescaled range method (Hurst, 1951; Peters, 1994; Kale, Butar Butar, 2011).

One of the procedures allowing the calculation of the fractal dimension $D(A)$ of the time series is the analysis of the rescaled range or, briefly, the R/S analysis (Hurst, 1951). This method first of all involves estimating the value of the Hurst exponent H^* (Chun et al., 2002) and then determining the fractal dimension according to the formula (Zwolankowska, 2000):

$$D(A) = 2 - H^*. \tag{2}$$

Another risk measure mentioned in the literature (Jajuga, 2007; Maginn et al., 2007; Bacon, 2008) is Value at Risk (VaR), which measures the largest expected loss in a given period for a given tolerance level. The determination of Value at Risk can be presented by the following formula:

$$P(W \leq W_0 - VaR) = \alpha, \tag{3}$$

where:
W – value of the financial instrument at the end of the period under consideration, defined as a random variable,
W_0 – current value of the financial instrument,
α – tolerance level.

From the equation (3) it follows that the probability of realizing a loss of a financial instrument equal to or greater than the VaR value is equal to the tolerance level α.

The value at risk depends on two parameters: the tolerance level and the period. The lower the tolerance level, the higher the value at risk, and if the longer the period, than the higher the value at risk (Jajuga, 2007). In addition to determining the above two parameters, it is necessary to select a method for modeling the probability distribution (Maginn et al., 2007). In the literature, there are three basic methods for estimating the quantile of the distribution: the variance-covariance method, the historical simulation method, and the Monte Carlo simulation method. The VaR method has become a standard in risk assessment. However, its disadvantages include: the difficulty of estimating the distribution of return rates and the lack of a preferred method for their estimation, frequent underestimation of the size and frequency of extreme negative return rates, failure to include positive return rates in the risk profile (Jajuga, 2007; Maginn et al., 2007).

4. Empirical analysis

The study analyzed the closing prices of futures contracts for commodities: WTI crude oil, natural gas, aluminum and gold. For this purpose, daily time series were prepared covering the period from the beginning of 2014 to December 2023. In order to check the level of investment risk depending on crisis situations, the entire period was divided into three separate sub-periods: Period 1 - before the Covid-19 pandemic (1 January 2018 - 28 February 2020), Period 2 - during the pandemic but before the armed conflict in Ukraine (01 March 2020 - 31 January 2022) and Period 3 - from the outbreak of the war to the end of 2023 (01 February 2022 - 31 December 2023). The entire six-year period was divided in this way to check how crisis conditions affect the level of investment risk.

The analysis of the time series of closing prices of futures contracts for the above-mentioned raw materials was carried out in the following stages:

1. Transformation of the time series into logarithms of the rates of return (Figure 3) according to the formula:

$$r_t = \ln(p_t/p_{t-1}), \tag{4}$$

where p_t is the price at time.

2. Estimation of Value at Risk (VaR) for rates of return.
3. Estimation of the fractal dimension for time series of rates of return based on the rescaled range analysis (R/S).
4. Analysis of the obtained results.

The logarithm of the rate of return is considered a measure of the profitability of an investment because it shows the investor how his investment is performing and thus allows him to control its course.

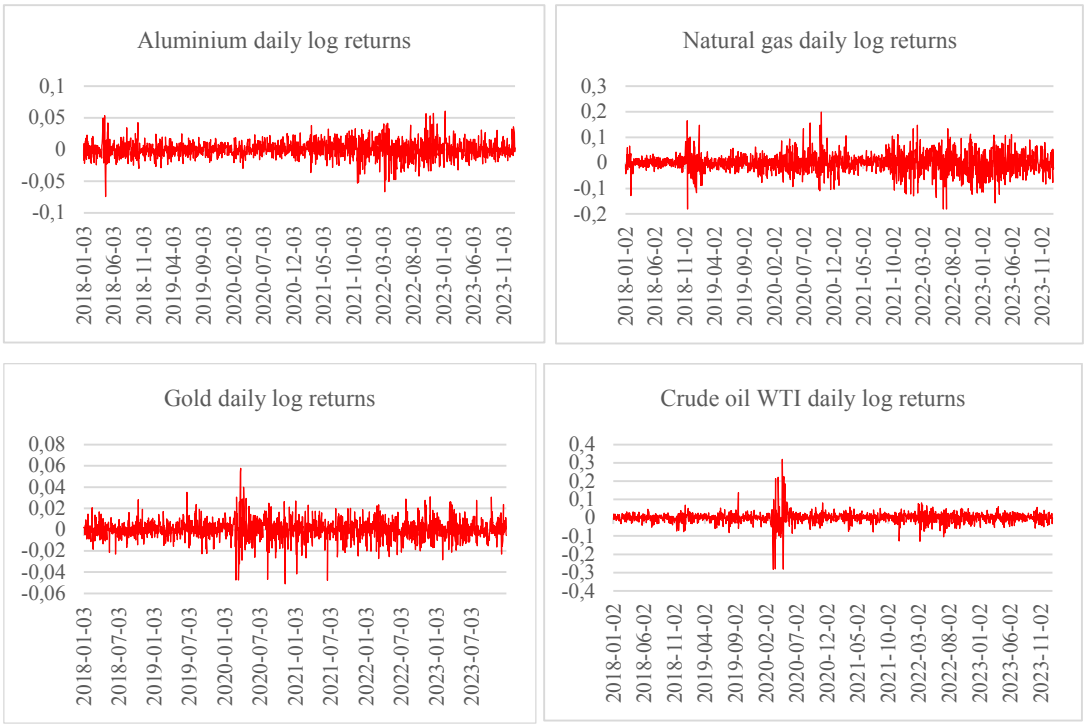

Figure 3. Logarithms of rates of return: aluminum, gold, natural gas and WTI oil in the period from 1 January 2018 to 31 December 2023.

Source: own study.

A frequently used measure of investment risk is Value at Risk (VaR). The higher the value of this measure, the higher the risk associated with a given financial instrument. Table 2 contains VaR values estimated for the logarithms of the rates of return of selected commodities over the last five years and for the three sub-periods described earlier.

Table 2.
Value at Risk Estimation Results – 0.95 Quantile

Series	VaR			
	Entire period	Period 1	Period 2	Period 3
Aluminium	0.022507131	0.01932597	0.020430061	0.027234908
Natural gas	0.064175002	0.045734167	0.065951185	0.078482455
gold	0.015648779	0.011976646	0.019265717	0.015233795
Crude oil WTI	0.051921685	0.032811538	0.072959545	0.043075583

Source: own study.

The results presented in Table 2 show that the highest VaR value, and thus the highest risk in the entire period, was characteristic of natural gas rates of return. Similar conclusions can be reached when considering individual sub-periods, where the value of this measure for this commodity was the highest (except for Period 2 (the pandemic period), where its value was slightly lower than the value obtained for crude oil). Since the outbreak of the war in Ukraine, VaR has been almost twice as high as in the period before the pandemic.

The next most risky raw material was crude oil. The highest VaR value for this commodity's rates of return could be observed during the Covid-19 pandemic. However, the value of this measure decreased in the third period and reached a level comparable to the period before the pandemic.

The least risky raw material turned out to be gold, for which the value at risk in the entire period and for individual sub-periods took the lowest values. The last commodity considered is aluminum, which was characterized by VaR values similar to gold throughout the period.

In the next step of the research, the fractal dimension was estimated using scaled range analysis. The obtained values are presented in Table 3.

Table 3.
Fractal dimension estimation results based on rescaled range analysis for selected commodity rates of return

Series	Fractal dimension			
	Entire period	Period 1	Period 2	Period 3
Aluminium	1.395234	1.510031	1.439266	1.420508
Natural gas	1.449525	1.419742	1.503644	1.427421
gold	1.383189	1.407909	1.425056	1.385273
Crude oil WTI	1.461215	1.435189	1.445621	1.540877

Source: own study.

Analyzing the results from Table 3, similar conclusions can be drawn as for value at risk. The riskiest investments were those related to crude oil and natural gas. The fractal dimension values for the entire six-year period for both commodities were the highest. However, it is worth noting that in the case of division into sub-periods, the value of the dimension estimated for crude oil assumed higher and higher values from period to period, while for natural gas the value of the fractal dimension increased during the pandemic, but decreased in the period related to the outbreak of the war in Ukraine. The opposite situation can be observed in the case of the data from Table 2, i.e. VaR values increased from period to period for natural gas, while in the case of crude oil they initially increased during the pandemic but decreased in the 3rd period.

Once again, gold had the lowest risk level, followed by aluminum, even though in the pre-pandemic period the fractal dimension estimated for aluminum was the highest.

5. Summary

The presented research results on investment risk assessment indicate a certain similarity in the interpretation of the results obtained on the basis of the fractal dimension and value at risk.

The most risky investments in the entire period (1 January 2018-31 December 2023) were futures contracts for natural gas and WTI oil. The least volatile were the financial series of

logarithms of the rates of return determined for gold futures contracts. This fact confirmed the general opinion that investments in gold are perceived as one of the safest in difficult periods.

The values of the measures determined for the sub-periods: before the Covid-19 pandemic, during it and after the outbreak of the war in Ukraine, confirmed the earlier conclusion about the most and least risky investments. These results reflect the fluctuations in commodity prices observed on their charts (a drop in WTI oil prices during the pandemic, followed by an increase in the prices of this commodity and natural gas during the armed conflict in Ukraine). This confirms the impact of crisis conditions on investment risk.

Fractal analysis used to assess investment risk can be an important complement to classical measures, but the research and considerations undertaken in this work do not exhaust all the issues related to the risk and efficiency of investments in the raw materials market and require further work.

References

1. Andronache, I.C., Peptenatu, D., Ciobotaru, A.M., Gruia, A.K., Gropoèilă, N.M. (2016). Using fractal analysis in modeling trends in the national economy. *Procedia Environmental Sciences*, *32*, pp. 344-351.
2. Bacon, C.R. (2008). *Practical portfolio performance measurement and attribution*. John Wiley & Sons.
3. Beckers, F., Verheyden, B., Couckuyt, K., Aubert, A.E. (2006). Fractal dimension in health and heart failure. *Biomed Tech. (Berl)*, *51*, pp. 194-197.
4. Bula, R. (2012). Aspekty metodyczne szacowania wymiaru fraktalnego finansowych szeregów czasowych. *Młodzi Naukowcy dla Polskiej Nauki*, *Vol. 2, No. 9*, pp. 192-200.
5. Buła, R. (2017). Analiza wymiaru fraktalnego spółek notowanych na Giełdzie Papierów Wartościowych w Warszawie – aspekty metodyczne. *Nauki o Finansach*, *1(30)*, pp. 9-27.
6. Chen, Y. (2013). A set of formulae on fractal dimension relations and its application to urban form. *Chaos, Solitons & Fractals*, *54*, pp. 150-158.
7. Chun, S.H., Kim, K.J., Kim, S.H. (2002). Chaotic Analysis of Predictability versus Knowledge Discovery Techniques: Case Study of Polish Stock Market. *Expert Systems*, *Vol. 19(5)*, pp. 264- 272.
8. Drozd, A. (2020). Ocena ryzyka i efektywności inwestycji na rynku metali szlachetnych. *Acta Universitatis Wratislaviensis*, *No 3991*, pp. 125-137.
9. Dubuc, B., Quiniou, J., Roques-Carmes, C., Tricot, C., Zucker, S.(1989). Evaluating the fractal dimension of profiles. *Physical Review A*, *Vol. 39, No. 3*, pp. 113-127.
10. Hurst, H.E. (1951). Long-term storage capacity of reservoirs. *Transactions of American Society of Civil Engineers*, *116*, pp. 770-799.

11. Jahanmiri, F., Parker, D.C. (2022). An Overview of Fractal Geometry Applied to Urban Planning. *Land*, *11*, *475*.
12. Jajuga, K. (2007). *Zarządzanie ryzykiem*, Warszawa: PWN.
13. Kale, M., Butar Butar, F. (2011). Fractal analysis of time series and distribution properties of Hurst exponent. *Journal of Mathematical Sciences & Mathematics Education*, *5(1)*, pp. 8-19.
14. Krężołek, D. (2020). *Modelowanie ryzyka na rynku metali*. Katowice: Wydawnictwo Uniwersytetu Ekonomicznego w Katowicach.
15. Lawrence, M.J., Sabra, A., Thomas, P. et al. (2015). Fractal dimension: A novel clot microstructure biomarker use in ST elevation myocardial infarction patients. *Atheroscler*, *240*, pp. 402-407.
16. Maginn, J.L., Tuttle, D.L., McLeavey, D.W. Pinto, J.E. (Eds.) (2007). *Managing investment portfolios: a dynamic process, Vol. 3*. John Wiley & Sons.
17. Mandelbrot, B. (2010). Fractal Financial Fluctuations. *Lesmoir-Gordon N.: The Colours of Infinity: The Beauty and Power of Fractals*. London: Springer-Verlag London Ltd.
18. Orzeszko, W. (2010), Wymiar fraktalny szeregów czasowych a ryzyko inwestowania. *Acta Universitatis Nicolai Copernici. Ekonomia XLI. Nauki Humanistyczno-Społeczne*, *397*, 57-70.
19. Peters, E.E. (1994). *Fractal Market Analysis*. New York: John Wiley & Sons.
20. Przekota G. (2022). Wymiar fraktalny szeregów czasowych szacowany metodą podziału pola. *Wiadomości Statystyczne. The Polish Statistician*, vol. 64, 9, 7–24.
21. Przekota, G. (2003). Szacowanie wymiaru fraktalnego szeregów czasowych metodą podziału pola. *Zeszyty Studiów Doktoranckich*, *z. 12.* Poznań, 47-68.
22. Sanchez-Granero, M.A., Fernandez-Martinez, M., Trinidad Segovia, J.E. (2012). Introducing fractal dimension algorithms to calculate the Hurst exponent of financial time series. *The European Physical Journal B*, *85, 3,* 1-13.
23. Sobolewska-Siemieniuk, M., Grabowska, S., Oczeretko, E., Kitlas, A., Borowska, M. (2007). Fractal analysis of mandibular radiographic images in the region of reincluded teeth. *Czas. Stomatol., 60, 5,* 93-600.
24. Sy-Sang, L., Feng-Yuan, C. (2009). Fractal dimensions of time sequences. *Physica A: Statistical Mechanics and its Applications*, *388(15),* 3100-3106.
25. Wang, H., Luo, S., Luo, T. (2017). Fractal characteristics of urban surface transit and road networks: Case study of Strasbourg, France. *Advances in Mechanical Engineering*, *9(2),* 1-12.
26. Zeug-Żebro, K. (2020). Investment risk assessment based on the long-term memory parameter. *Zeszyty Naukowe Politechniki Śląskiej, Seria: Organizacja i Zarządzanie*, *No. 144,* 671-680.
27. Zwolankowska, M. (2000). Metoda segmentowo-wariacyjna. Nowa propozycja liczenia wymiaru fraktalnego. *Przegląd Statystyczny*, *no. 1-2*, 209-224.

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