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CONTENTS

Foreword	7
1. Honorata BALICKA, Jerzy BALICKI – Quantum artificial intelligence in management of selected business processes	9
2. Rafał BUŁA – Differences in intertemporal preferences for money and environmental goods: the case of Poland	27
3. Katarzyna CZAINSKA, Daniel BIERNAT – Use of social media and artificial intelligence in creating the image of a leader in a local government election campaign	41
4. Marta DAROŃ – Sustainable practices in enterprises in the context of ICT devices usage	61
5. Justyna DĄBROWSKA – Evolving role and performance of science and technology parks in innovation systems: a quintuple helix perspective	71
6. Ewa DZIWOK, Witold SZCZEPANIAK – Multi-dimensional systemic risk measure under exogenous shocks including climate change	83
7. Maciej GONISZEWSKI – Efficiency, profitability and credit action of state and private banks during covid-19 and the war in Ukraine	103
8. Maciej JAGÓDKA – Barriers for Industry 4.0 in emerging economies – the case of Poland	133
9. Adam KIERSZTYN, Dariusz CZERWIŃSKI, Ernest CZERMAŃSKI, Aneta ONISZCZUK-JASTRZĄBEK, Konrad SMOLIŃSKI, Patrycja MIAZEK, Tomasz LASKOWICZ, Jakub JANKIEWICZ, Agnieszka RZEPKA, Radosław MIŚKIEWICZ – Data integrity analysis on the example of AIS database	155
10. Patrycja KOKOT-STĘPIEŃ – Financial aspects of innovation activity of enterprises	171
11. Dominika KOŁODZIEJ – Human resources strategies and organisational resilience in selected publicly traded companies	183
12. Magdalena KOWALSKA, Marzena PAPIERNIK-WOJDERA, Agata GNIADKOWSKA-SZYMAŃSKA – The sustainable entrepreneurship and socio-economic cohesion in Poland	197
13. Agnieszka KOWALSKA-STYCZEŃ, Kinga JUSZCZYK – Preparing business analysts for the modern job market: a comparative analysis of skills and education ...	215
14. Łukasz Jarosław KOZAR, Grzegorz BEDNARSKI, Gabriela CHOMICZ, Michał CHRZANOWSKI, Daniel JAKSIK, Krystian KRĘGIEL, Michał KULAWCZYK, Kacper ŚMIETANA – Shaping green competences of transport and logistics employees through green activities	233
15. Piotr KUSZEWSKI – Strategic use of costly innovation	253

16. Aleksandra KUZIOR, Mariya SIRA – Revolutionizing management: competency building with cutting-edge technologies	273
17. Daria MACIEJEWSKA, Dawid OLEWNICKI, Jerzy GĘBSKI, Michał ROMAN, Piotr LATOCHA – Consumer preferences in the context of possible organization of enotourism services in central Poland	289
18. Klaudia MICOR, Roksana POLOCZEK – MOQ models review in perspective of 7 wastes	311
19. Chrystyna MISIEWICZ, Krzysztof STEPANIUK – Consumer activism on social media during geopolitical conflict	331
20. Bartosz MISIUREK – Methodology for assessing employee predispositions to types of jobs in order to reduce turnover in manufacturing enterprises	351
21. Paweł MROWIEC – Awareness and development of green-blue infrastructure in the process of urban management in the GZM area in the light of own research	367
22. Marcin MROWIEC – Safe-haven currencies during financial market instability in the 21st century	385
23. Anna MULARCZYK – Analysis of the energy mix in Poland and the European Union in terms of renewable energy prospects	399
24. Rafał NAGAJ – Green deal as one of the determinants of energy poverty	421
25. Tomasz L. NAWROCKI, Mariusz ZIELIŃSKI – Analysis of human capital efficiency in Polish energy companies	437
26. Piotr NOWACZYK – The essence of the process of organizing and managing tourist expenses of cruise ship passengers case study seaport in Kołobrzeg	463
27. Jadwiga NYCZ-WRÓBEL – Best practises in environmental management among the Polish public administration bodies participating in the EMAS scheme	477
28. Beata OLEKSIK, Grzegorz SIWIEC, Roksana POLOCZEK, Klaudia MICOR – The impact of selected passenger car models on environmental elements	493
29. Marzena PAPIERNIK-WOJDERA, Renata PISAREK-BARTOSZEWSKA – Credit position of logistics sector companies in Poland in the context of macroeconomic conditions	507
30. Beata PATER – Organization of the emergency medical service in Poland	521
31. Agnieszka PIOTROWSKA-PUCHAŁA – Modern management systems in enterprises	531
32. Roksana POLOCZEK – Balancing efficiency and flexibility – a simulation of line configurations	541
33. Patrycja ROGOWSKA – Constraints in printing industry	555
34. Alina RYDZEWSKA – Green investments as a way to support sustainable development or to earn?	565
35. Sylwia SIERACKA, Piotr GRUDOWSKI – Strategic partnerships in the development of the polish biotechnology industry	579

36. Olga SOBOLEWSKA – Key factors influencing cooperation in a networked organization	593
37. Ewa SZATANIAK – Occupational health and safety management in the police: challenges and practices in the context of modern occupational hazards	605
38. Emil ŚLĄZAK – AI-driven innovation in banking – the case of cognitive RPA	619
39. Elżbieta WAŻNA – The role of artificial intelligence in the employee recruitment process	631
40. Tomasz WĘGRZYN, Bożena SZCZUCKA-LASOTA, Adam JUREK – TIG welding of titanium alloy Ti-6Al-4V for automotive applications	643
41. Joanna ZABAWA-KRZYPKOWSKA, Agnieszka PLUSZCZEWICZ-FORNAL, Krzysztof GROŃ – Workshop activities as an essential part of architectural education. Mosaic	651
42. Brigita ŽUROMSKAITĖ-NAGAJ – Gen Z values and their preferences for a changing labour market	667

FOREWORD

Presented number of Silesian University of Technology. Scientific Papers. Organization and Management Series. Presented papers contain result of researches conducted by various universities. The number consists of 42 papers.

The papers presented in the number concentrate on many topics connected with organization and management. There are in the number papers about: artificial intelligence usage in management, sustainability, innovation management, risk management, impact of COVID-19 pandemic on management, Industry 4.0, human resources management, entrepreneurship, logistics, strategic management, services management, finances, tourist management, industry management and occupational health and safety management.

Radosław Wolniak

QUANTUM ARTIFICIAL INTELLIGENCE IN MANAGEMENT OF SELECTED BUSINESS PROCESSES

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Purpose: The aim of the article is to present potential applications of Quantum Artificial Intelligence (QAI) in enhancing Business Process Management (BPM), with a particular focus on predictive analytics.

Design/methodology/approach: The primary research methods include a critical analysis of the literature. Deep neural network testing was also conducted to identify efficient predictors and detectors for BPM systems. In addition, intensive computational experiments were carried out to analyze the quality of solutions defined by the proposed quantum-inspired algorithms.

Findings: The results of theoretical research and numerical experiments confirmed that QAI technology, developed within cutting-edge machine learning models and natural language processing (NLP), has a significant impact on enhancing BPM. In the context of predictive analytics in BPM systems, quantum predictive models trained on neural networks play a key role in increasing forecast accuracy. Furthermore, leveraging the power of NLP for task automation enables to extract insights and optimize processes, ultimately achieving business objectives more efficiently.

Practical implications: The obtained results form the basis for recommendations on how QAI models, developed within machine learning and NLP, can enhance not only current business processes but, most importantly, predictive analysis.

Social implications: By implementing QAI effectively and consistently, organizations can improve decision-making based on precise data analysis rather than relying on intuition or the experience of decision-makers.

Originality/value: The authenticity of the research results stems from clear ideas for the effective use of quantum technologies developed in the fields of machine learning and NLP to enhance BPM, particularly in the area of predictive analytics.

Keywords: process optimization, quantum predictive analytics, intelligent decision support.

Category of the paper: research paper.

1. Introduction

Business Process Management (BPM) should optimize various crucial business processes to enhance efficiency, agility, and performance. BPM involves analyzing and modeling business processes to achieve strategic business objectives. Besides, designing and implementing critical tasks provide additional solutions to meet important deadlines. Furthermore, it is also important to monitor and continuously improve processes in order to achieve the appropriate goals faster. Integrating artificial intelligence (AI) into BPM enables organizations to streamline operations, improve decision-making and enhance customer experiences (Lotko, 2022). Moreover, it enables achieving greater agility and competitiveness in a dynamic business environment (Bartlett, Kabir, Han, 2023).

Recently, quantum computing has been developing very intensively, resulting in the creation of quantum artificial intelligence (QAI), which refers to applying quantum computing principles to augment the capabilities and performance of artificial intelligence systems. QAI uses the unique properties of quantum mechanics to solve computational problems more efficiently than classical methods. Therefore, it has a great potential to enhance several aspects of business process management (Beheshti, Yang, Sheng et al., 2023), in particular, improving business analytics (Wolniak, 2024).

The groundbreaking nature and revolutionary potential of quantum technologies in the context of business process management are beyond doubt, while the scarcity of empirical research in this field highlights the urgency and importance of addressing such topics (Lotko, 2005a). Therefore, the subject of Quantum AI in managing selected business processes, explored in this article, holds not only significant theoretical value but also immense practical potential (Lotko, 2005b). Its interdisciplinary nature, innovativeness, and relevance to modern enterprises and the global economy make it one of the key research areas of the 21st century. Quantum AI integrates advanced computing, quantum mathematics, management, and organizational theories, positioning research on Quantum AI as interdisciplinary and transcending the boundaries of a single discipline, contributing to the advancement of both technical and social sciences.

Moreover, the development of QAI technologies aligns with global trends in the digitalization of the economy and the search for innovative tools to support sustainable development. Quantum AI, as a technology of the future, addresses challenges such as the need to process massive datasets (big data), the growing complexity of management systems, and the necessity for real-time decision-making (Gajdzik, Wolniak, Grebski, 2024).

Quantum AI not only accelerates processes but also facilitates more accurate decision-making in dynamic environments. Quantum algorithms, such as quantum optimization and quantum machine learning, enable the resolution of problems that are beyond the capabilities of classical computational methods. This is particularly crucial in areas like supply chain

optimization, market forecasting, and real-time personalization of products and services. Applications based on Quantum AI technology not only enhance efficiency but also help businesses respond more effectively to market changes, which is critical in a rapidly evolving business environment. In this context, Quantum AI can have specific applications in managing processes such as predicting consumer behavior, optimizing dynamic pricing strategies, and managing financial risk in real-time (Hassan et al., 2024).

Quantum AI technologies hold strategic importance for the economy and the competitiveness of enterprises. The implementation of quantum technology in management can provide a significant competitive advantage. In the face of global technological competition, Quantum AI in business process management is becoming a critical tool for enhancing efficiency and innovation within companies (Wolniak, 2023).

Quantum technologies can be developed in machine learning and natural language processing (NLP) to improve and automate repetitive tasks within business processes. By implementing this strategy effectively and consistently, organizations can strengthen their competitive position, drive growth, and thrive in dynamic and competitive markets. Moreover, QAI can analyze historical data to predict future outcomes and trends that can help forecast demand, identify potential bottlenecks or failures in processes, and optimize resource allocation. The great potential of QAI concerns applications in business process analysis that involve identifying and understanding the current state of business processes within an organization. It includes gathering data, mapping out workflows, and identifying areas for improvement by QAI (Beerepoot et al., 2023).

For example, quantum computing can also help optimize smart city systems by enabling faster processing of large amounts of data, improving the efficiency of various city services, such as transportation and energy management (Gajdzik, Wolniak, Grebski et al., 2024). Moreover, quantum sensing technologies can be used to improve the accuracy of measurements and monitoring in smart cities, such as detecting changes in air quality, water levels, or traffic flow (Balicka, 2023b; Balicka, 2020). Moreover, while quantum tools are still in their early stages of development, their potential for improving the functionality and efficiency of smart city infrastructure is substantial (Wolniak, Stecuła, 2024; Bocciarelli, D'Ambrogio, Panetti, 2023).

This paper presents solutions for how quantum artificial intelligence models can improve some fields of BPM. Related work is submitted in Section II. Then, the quantum solutions are characterized in Section III. Next, Section IV presents some studies under predictive analytics by quantum processors. Predictive analytics in BPM can help organizations anticipate process failures, optimize resource allocation, and improve decision-making. Natural Language Processing (NLP) in BPM systems is described in Section V. Finally, the important conclusions and future work are discussed in Section VI.

2. Related Work

BPM is concerned with analyzing, designing, and managing work processes within and across organizations, which often involves information technology. Beerepoot et al. discussed the biggest business process management problems that must be solved. The first crucial problem relates to digital innovation, particularly the BPM-driven value creation from data. The data deluge and associated technological proliferations have considerably changed the landscape of how businesses are run (Beerepoot et al., 2023). Digital business transformation plays a crucial role in achieving sustainable development and supporting intelligent production processes (Gajdzik, Wolniak, Grebski et al., 2024). The efficient processing of an increasing volume of data, including leveraging the potential of QAI, plays a crucial role, particularly in the development of predictive analytics. Quantum technologies combined with predictive analytics have the potential to revolutionize business process management, particularly in the areas of optimization, monitoring, and event prediction (Wolniak, 2023b). To fully harness their potential, organizations should begin exploring practical applications of these technologies, for example, through proof-of-concept models, to gain a competitive edge in the emerging digital era. Artificial intelligence supported by quantum technologies can be applied across various areas of business process management (Lei et al., 2016).

Another problem is an expansive BPM. Despite large investments in BPM, organizations are still left with process fragments by seeing ‘process trees’ rather than the entire ‘BPM forest’. This was evident during the COVID-19 pandemic, with organizations struggling with many ad-hoc and often uncoordinated process changes. BPM approaches that put individual processes at the center of their attention are unlikely to be able to address ‘big processes’, i.e., processes that stretch far beyond the boundaries of an enterprise, are closely intertwined with other processes, and are impacted by various management disciplines (Lei et al., 2016).

Moreover, the problem of automated process redesign is still important. Despite all automation efforts, process redesign has remained a manual, cognitively demanding task, making it time-consuming, labor-intensive, and error-prone. Constructing digital twins supports business processes due to various factors. This particular problem arises in the context of planned changes. It may include reordering two or more tasks, adding a task, adding a resource, changing the decision logic of a branching point, or automating a task. These changes may positively or negatively impact performance measures, e.g., cycle time, activity processing time, or resource utilization (Lei et al., 2016).

Bartlett, Kabir, and Han presented a review on Business Process Management system design subject to the role of virtualization and work design (Bartlett, Kabir, Han, 2023). This study explored the integration of BPM, virtualization, and work design to enhance organizational performance and productivity. Virtualization and work design in BPM systems may enhance flexibility, scalability, and agility. Organizations can effectively respond to

dynamic business needs and market conditions by leveraging virtual resources, thus eliminating the constraints of physical proximity. An analysis revealed promising avenues for future research, emphasizing the role of usability in BPM system design and its impact on task accomplishment. A holistic approach to BPM system design has emerged as crucial, encompassing process modeling, automation, workflow management, integration, analytics, reporting, governance, and continuous improvement (Bartlett, Kabir, Han, 2023).

Chang, Chen, Xu, and Xiong compared various BPM tools (Chang et al., 2023). The benefits of integrating BPM tools into businesses are presented, too. Three BPM tools, namely Bizagi BPM Suite, ProcessMaker and Flokzu are analyzed on a real business process. Among the tools evaluated, Bizagi and Flokzu have a more intuitive user interface, and Process Maker is the least user-friendly tool. Bizagi is recommended for large and middle-sized organizations and Flokzu for smaller organizations (Chang et al., 2023).

AI-augmented BPM systems are an emerging class of process-aware information systems empowered by trustworthy AI technology because they enhance the execution of business processes to make these processes more adaptable, proactive, explainable, and context-sensitive. A vision of this system is presented in (Dumas et al., 2023). Besides, the lifecycle of processes, core characteristics, and a set of challenges to realize systems are studied, too.

Dunzer, Tang, Höchstädter, Zilker, and Matzner described design principles for using BPM systems to achieve operational excellence to reduce costs and improve the quality of their business processes (Dunzer et al., 2023). This study follows an action design research approach to design these systems with a medium-sized company. There are concurrently evaluated tracking performance indicators aligned with the company's objective. Moreover, seven design principles are discussed to improve business processes continuously. These design principles comprise user management, process modeling, automation, logging, monitoring, integration, and case handling (Dunzer et al., 2023).

We can see that artificial intelligence can be utilized in Business Process Management in several ways to improve efficiency, accuracy, and decision-making (Balicka, 2023a). AI technologies like robotic process automation (RPA) can automate repetitive and rule-based tasks within business processes. AI-powered bots can perform tasks such as data entry, document processing, form filling, and basic decision-making. Smart algorithms can analyze historical process data to identify inefficiencies, bottlenecks, and opportunities for optimization. Machine learning techniques can predict process outcomes, forecast resource requirements, and optimize process parameters to improve overall performance.

BPM data fusion involves several stages: acquisition, preprocessing, feature extraction, data fusion, and decision-making. Each stage involves specific algorithms and techniques to handle and integrate the various data types into a unified framework. We can say that data fusion is a critical aspect of system development, as it allows city organizations to leverage the vast amounts of data generated by various systems and devices to make informed decisions, improve efficiency, and enhance the quality of life for residents (Akan, 2023).

Besides, quantum artificial intelligence can support important systems like monitoring complex infrastructure, the guidance of autonomous vehicles, smart buildings, and medical diagnosis. Techniques for quantum-inspired multi-sensor data fusion use algorithms and rules of machine learning, statistical estimation, and pattern recognition (Balicki, 2023; Taherdoost, Madanchian, 2024).

Big Data changes the approach to BPM by integrating data from many sources to produce comprehensive and specific unified data (Balicki J., Balicka H., Dryja, 2021; Ayed, Halima, Alimi, 2015). Therefore, the quality of Big Data in organizations depends on services provided by some public platforms (Durán, Pozas, Rocha, 2024; Saif et al., 2023). Deep learning algorithms can be effectively used (Ji et al., 2013). Artificial neural networks are used not only to improve processes but also to model them (Lotko, 2018). However, deep artificial neural networks are usually developed for classification, clustering, and prediction, and we recommend improving their metrics by using quantum mechanisms (O'Leary, 2013; Zhou et al., 2010).

BPM uses recommendation systems, too. Ravi, Subramaniaswamy, Varadharajan, Gao, and Indragandhi proposed a hybrid quantum-induced swarm intelligence clustering for the urban trip recommendation in a smart city (Ravi et al., 2018). This novel user clustering approach is based on Quantum-behaved Particle Swarm Optimization for the collaborative filtering-based recommender system. The recommendation approach has been evaluated on real-world, large-scale datasets of Yelp and TripAdvisor for hit rate, precision, recall, f-measure, and accuracy. The evaluation results prove the usefulness of the generated recommendations and depict the users' satisfaction with the proposed recommendation approach (Marz, Warren, 2014; Ravi et al., 2018).

Blockchain is a very useful technique that can securely organize diverse organizational processes. Chen, Gan, Hu, and Chen studied the construction of a post-quantum blockchain for organizations (Chen et al., 2020). It finds wide applications, especially in distributed environments, where entities such as wireless sensors must be certain of the server's authenticity. As contemporary blockchain techniques that address concerns have not been designed, a blockchain is proposed in the post-quantum setting. It seeks to discover how it can resist attacks from quantum computing (Chen et al., 2020).

3. Quantum solutions

Quantum AI and quantum machine learning can be used to analyze historical process data and identify patterns, trends, and correlations that can help predict future process behavior. Predictive analytics can be applied to forecast demand, identify customer preferences, anticipate maintenance needs, and optimize resource allocation within business processes. AI-powered decision support systems can assist human decision-makers by providing real-time

insights, recommendations, and predictions based on process data analysis. These systems can help optimize decision-making in areas such as resource allocation, risk management, pricing, and strategic planning.

Natural Language Processing (NLP) systems enable computers to understand, interpret, and generate human language, which can be valuable in BPM for tasks such as text analysis, sentiment analysis, and information extraction from unstructured data sources such as emails, customer feedback, and social media. Beheshti, Yang, and Sheng, et al. proposed transforming business process management with generative artificial intelligence, using Generative Pre-trained Transformers (GPT) (Beheshti, Yang, Sheng et al., 2023).

Generative Pre-trained Transformer is a state-of-the-art machine learning model capable of generating human-like text through natural language processing (NLP) (Beheshti, Yang, Sheng et al., 2023). GPT is trained on massive amounts of text data and uses deep learning techniques to learn patterns and relationships within the data, enabling it to generate coherent and contextually appropriate text. We can use the GPT technology to generate new BPM models. ProcessGPT has the great potential to enhance decision-making in data-centric and knowledge-intensive processes in organizations. The model can be integrated with NLP and machine learning techniques to provide insights and recommendations for process improvement. Furthermore, the model can automate repetitive tasks and improve process efficiency, enabling knowledge workers to communicate analysis findings and supporting evidence and make decisions. It offers a powerful tool for process augmentation, automation, and improvement. It demonstrated how ProcessGPT can be a powerful tool for augmenting data engineers in maintaining data ecosystem processes within large bank organizations. A scenario highlights the potential of this approach to improve efficiency, reduce costs, and enhance the quality of business operations through the automation of data-centric and knowledge-intensive processes. These results underscore the promise of ProcessGPT as a transformative technology for organizations looking to improve their process workflows (Beheshti, Yang, Sheng et al., 2023). Introducing quantum technology to ProcessGPT may increase the efficiency of that approach.

QAI can be used to continuously monitor business processes in real time and detect anomalies, deviations, and potential issues. Algorithms can trigger alerts, notifications, and automated responses when predefined thresholds or conditions are met, allowing organizations to address problems and maintain process quality proactively. QAI-powered systems can analyze customer data to personalize and customize the customer experience throughout the BPM lifecycle. This can include personalized product recommendations, targeted marketing campaigns, dynamic pricing strategies, and tailored customer support interactions (Li, Chosler, 2007; Li et al., 2018).

QAI technologies can enable dynamic and adaptive business processes that can automatically adjust and reconfigure themselves in response to changing conditions, requirements, and objectives. This flexibility allows organizations to quickly respond to market dynamics, regulatory changes, and customer preferences while maintaining process efficiency and effectiveness (Lei et al., 2016).

By leveraging AI technologies in BPM, organizations can streamline operations, improve decision-making, enhance customer satisfaction, and gain a competitive edge in today's rapidly evolving business landscape. Deep neural networks and the Internet of Things are based on technological trends that can reshape the BPM systems. These technological trends increasingly influence each other because IoT can transmit less data to make better decisions. These technologies will allow decision-makers to access, process, and deliver data more efficiently, providing enhanced and personalized experiences. Advances in deep learning are critical to turn information into knowledge and to embed autonomy and intelligence into organizations. At the current moment of the city monitoring, thousands of sensors create the complex image of the organization that can change dynamically. The size of these images are constrained by the computational cost of deep learning (Zhou et al., 2010).

Figure 1 shows training progress of an neural network after feature selection for the German Traffic Sign Detection Benchmark Dataset. The network identifies the traffic sign from images on German roads (Schmidhuber, 2014).

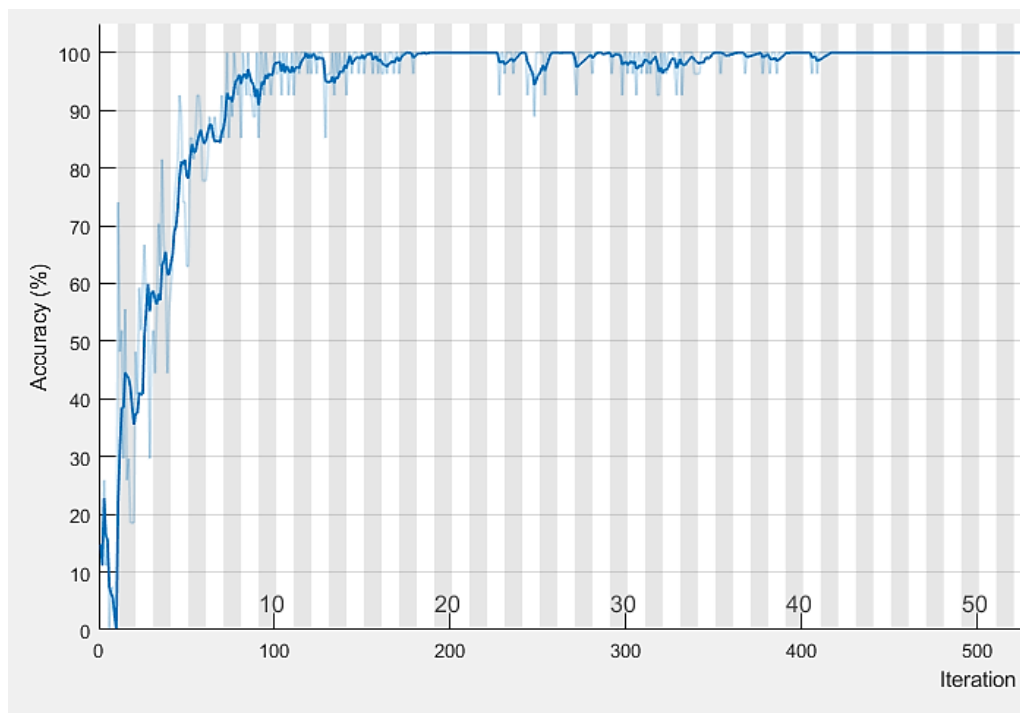


Figure 1. The accuracy improvement by the neural network training for the German Traffic Sign Detection Benchmark Dataset.

Source: Own study.

In an organization, the Internet of Things connects an output layer of distributed sensors with edge devices and a core layer of cloud servers (Figure 2). IoT alters the trusted interaction between citizens, services, and applications with the sensors embedded into the real-world environment. Social networks, advanced artificial intelligence, and cloud platforms change the standards of producing, consuming, and interacting with content, services, and objects. They are the new approach for our societies related to communication, exchange, business,

and knowledge management. Advances in language technologies decrease language barriers. Besides, deep learning can be personalized and tailored to each citizen's needs, competencies, and abilities (Krizhevsky, Sutskever, Hinton, 2012).

Figure 2 shows a diagram of data fusion with the Internet of Things in an organization. Education and information of citizens are important to understand and use collective intelligence to make efficient decisions. Data fusion provides accurate information from sensors via IoT to the edge layer devices and the BPM cloud servers. By combination of data fusion with the IoT, we can create new innovative models of BPMs.

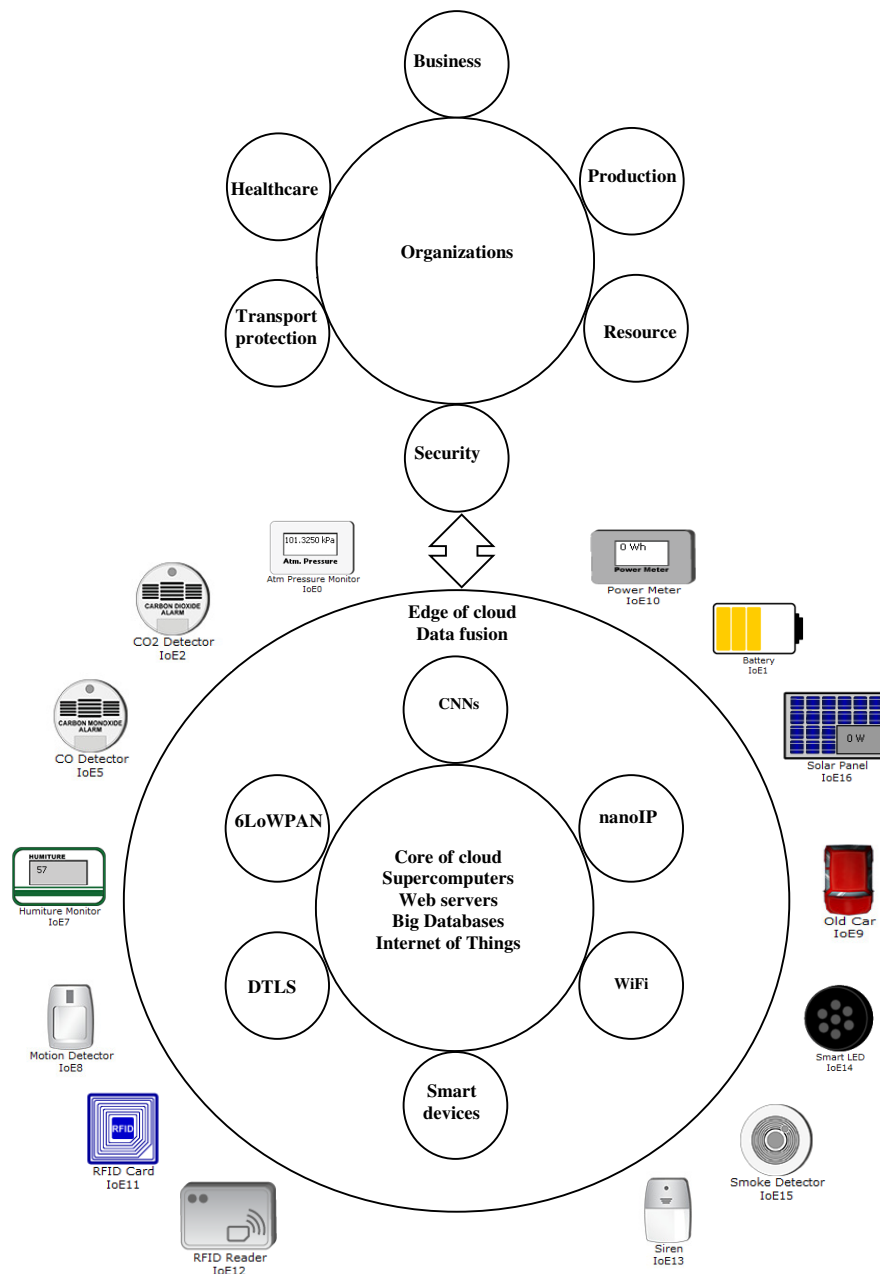


Figure 2. Internet of Things for supporting BPM system.

Source: Own study.

4. Quantum Predictive Analytics

Predictive analytics in BPM systems uses data from the organization's environment to predict future events or outcomes. It involves extracting patterns, trends, and relationships from past data to forecast likely future scenarios. Data is collected from various sources and can include historical records, transactional data, customer interactions, sensor data, social media data, and more. Data needs to be cleaned, processed, and prepared for analysis. This involves removing duplicates, handling missing values, normalizing data, and transforming variables.

Feature selection involves identifying the most relevant features that have predictive power and removing irrelevant or redundant ones. The predictive model is trained using historical data, where the input features and corresponding target values are used to train the model. During training, the model adjusts its parameters to minimize the difference between the predicted and actual values. The model can be used to make predictions on new, unseen data. The model takes the input features from new data instances and generates predictions for the target variable (Tian et al., 2023).

Predictive models are deployed into production systems where they can generate real-time predictions. Models are regularly monitored to ensure their accuracy and reliability. They can be retrained or updated with new data to maintain their effectiveness (Zhao, 2017).

Predictive analytics has numerous applications across BPM. It can be used for various tasks such as customer churn prediction, sales forecasting, risk assessment, fraud detection, demand forecasting, predictive maintenance, and personalized recommendations. BPM systems require powerful technologies based on the AI paradigm (Gadatsch, 2023). The open issue is the balancing of deep artificial neural network workload among edge and cloud servers (Węglarz, Błażewicz, Kovalyov, 2006). Figure 3a) shows minimization both the CPU workload of the bottleneck computer (denoted as $\hat{Z}_{max}$) and the communication workload of the bottleneck server ($\tilde{Z}_{max}$) for BPM predictive analytics (Balicki, 2022).

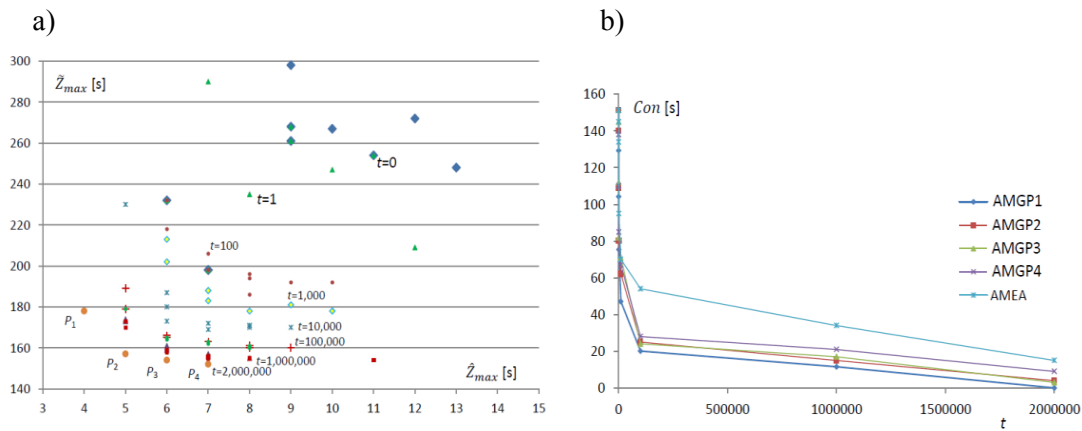


Figure 3. Evolution and convergence: a) Migration of evaluations towards the Pareto front; b) Outcomes convergences for some multi-objective algorithms.

Source: Own study.

5. Natural Language Processing in BPM systems

NLP technologies in BPM systems can unlock new capabilities, improve operational efficiency, enhance customer engagement, and drive innovation across the entire process lifecycle. NLP enables organizations to harness the power of natural language to automate tasks, extract insights, and optimize processes, ultimately enabling them to achieve their business objectives more effectively and competitively.

NLP-powered sentiment analysis can be used to analyze customer feedback, social media mentions, and online reviews to gauge customer sentiment, identify emerging trends, and detect potential issues or opportunities within business processes. By integrating sentiment analysis into BPM systems, organizations can monitor customer perceptions, prioritize actions, and continuously improve customer experience.

NLP techniques such as information retrieval, question answering, and knowledge graph analysis can facilitate knowledge management and discovery within BPM. Organizations can enhance knowledge sharing, collaboration, and decision support across business processes by automatically indexing, categorizing, and summarizing knowledge assets such as documents, wikis, and knowledge bases.

To extend features of NLP, we introduce quantum improvements. A qubit can exist in more than one state (a superposition), and can be represented by the Bloch sphere. We use Bra-ket (or Dirac) notation. The inner (or dot) product of two states can be denoted as a bracket $\langle \alpha | \beta \rangle$. The qubit can be modeled as a two-layer quantum bit from the Hilbert space H_2 with the base $B = \{|0\rangle, |1\rangle\}$. The qubit may be in the “1” binary state, in the “0” state, or in any superposition of them (Arute et al., 2019). The state x_m of the m th qubit in the *register* can be written, as follows (Arute et al., 2019):

$$Q_m = \alpha_m |0\rangle \oplus \beta_m |1\rangle, \quad (1)$$

where:

α_m and β_m – the complex numbers that specify the amplitudes of the states 0 and 1, respectively;

$\oplus$ – a superposition operation;

m – the index of the qubit, $m = \overline{1, M}$.

The value $|\alpha_m|^2$ is the probability that we observe the state “0”. Similarly, $|\beta_m|^2$ is the probability that state “1” is measured. The qubit is characterized by the pair (α_m, β_m) with the constraint, as below (Balicki, 2023):

$$|\alpha_m|^2 + |\beta_m|^2 = 1 \quad (2)$$

Dirac notation is often used to select a basis. The basis for a qubit (two dimensions) is $|0\rangle = (1,0)$ and $|1\rangle = (0,1)$. An alternative common basis consists of the eigenvectors of the *Pauli-x* operator: $|+\rangle = \frac{1}{\sqrt{2}}(1,1)$ and $|-\rangle = \frac{1}{\sqrt{2}}(1,-1)$. The most commonly used representation of a quantum register is the matrix, as follows:

$$Q = \begin{bmatrix} |\alpha_1| & \dots & |\alpha_m| & \dots & |\alpha_M| \\ |\beta_1| & \dots & |\beta_m| & \dots & |\beta_M| \end{bmatrix} \quad (3)$$

However, the state $Q_m = \alpha_m|0\rangle \oplus \beta_m|1\rangle$ of the m th qubit can be represented as the point on the 3D Bloch sphere (Figure 4), as follows (Balicki, 2022):

$$|Q_m\rangle = \cos \frac{\theta_m}{2} |0\rangle + e^{i\phi_m} \sin \frac{\theta_m}{2} |1\rangle, m = \overline{1, M} \quad (4)$$

where: $0 \leq \theta_m \leq \pi$ and $0 \leq \phi_m \leq 2\pi$.

Two angles θ_m and ϕ_m determines the localization of m th qubit on the Bloch sphere. The North Pole represents the state $|0\rangle$, the South Pole represents the state $|1\rangle$, and the points on the equator represent all states in which 0 and 1 are the same. Thus, in this version of the quantum-inspired genetic algorithm, M Bloch spheres represent the gene states. In addition to the representation of (3), we can, therefore distinguish the following other models of the register:

$$Q^{sign} = \begin{bmatrix} |\alpha_1| & \dots & |\alpha_m| & \dots & |\alpha_M| \\ \text{sign}(r_1) & \dots & \text{sign}(r_m) & \dots & \text{sign}(r_M) \end{bmatrix} \quad (5)$$

where: r_m – the random number from the interval $[-1; 1]$.

$$Q^{vector} = [|\alpha_1|, \dots, |\alpha_m|, \dots, |\alpha_M|] \quad (6)$$

$$Q^{angle} = \begin{bmatrix} \theta_1 & \dots & \theta_m & \dots & \theta_M \\ \phi_1 & \dots & \phi_m & \dots & \phi_M \end{bmatrix} \quad (7)$$

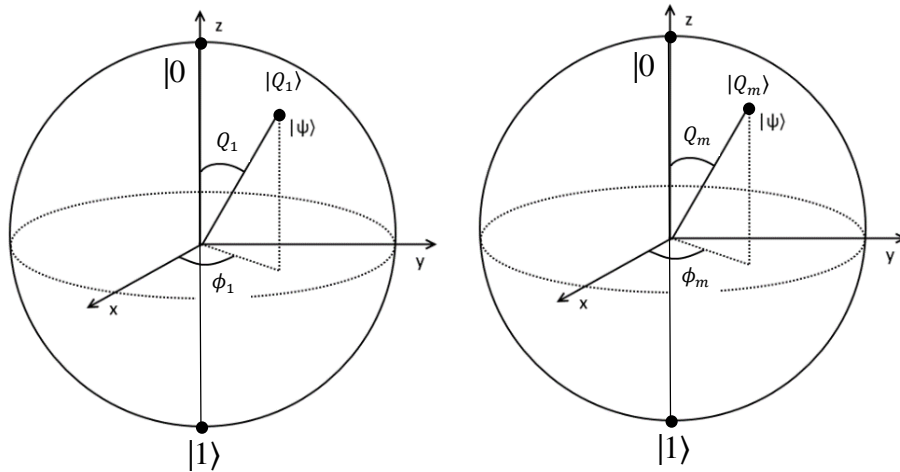


Figure 4. The Bloch spheres of the quantum register with M qubits.

Source: Own study.

There are two important criteria for deep learning. The first one is accuracy, and the second criterion is the F1 score. We evaluate their values due to each epoch. Afterward, we evaluate the fitness of each binary chromosome by using the ranking procedure with non-domination

sorting. We determine non-dominated solutions from the current population and copy them to the archive after verification.

A rotation gate R_y is a single-qubit rotation through the positive or negative angle θ_m [radians] around the y-axis, as follows (Balicki, 2023):

$$R_y(\theta_m) = \begin{bmatrix} \cos\left(\frac{\theta_m}{2}\right) & -\sin\left(\frac{\theta_m}{2}\right) \\ \sin\left(\frac{\theta_m}{2}\right) & \cos\left(\frac{\theta_m}{2}\right) \end{bmatrix} \quad (8)$$

Besides, we can define a rotation gate R_x around the y-axis, as follows:

$$R_x(\theta_m) = \begin{bmatrix} \cos\left(\frac{\theta_m}{2}\right) & -i \sin\left(\frac{\theta_m}{2}\right) \\ -i \sin\left(\frac{\theta_m}{2}\right) & \cos\left(\frac{\theta_m}{2}\right) \end{bmatrix} \quad (9)$$

To complete these operators, we introduce a rotation gate R_z around the z-axis, as follows:

$$R_z(\theta_m) = \begin{bmatrix} e^{-\frac{\theta_m}{2}} & 0 \\ 0 & e^{\frac{\theta_m}{2}} \end{bmatrix} \quad (10)$$

Figure 5 shows the modification of the quantum register by Hadamard gates and rotation gates R_x , R_y , and R_z by quantum processor Starmon-5 (Balicki, 2023).

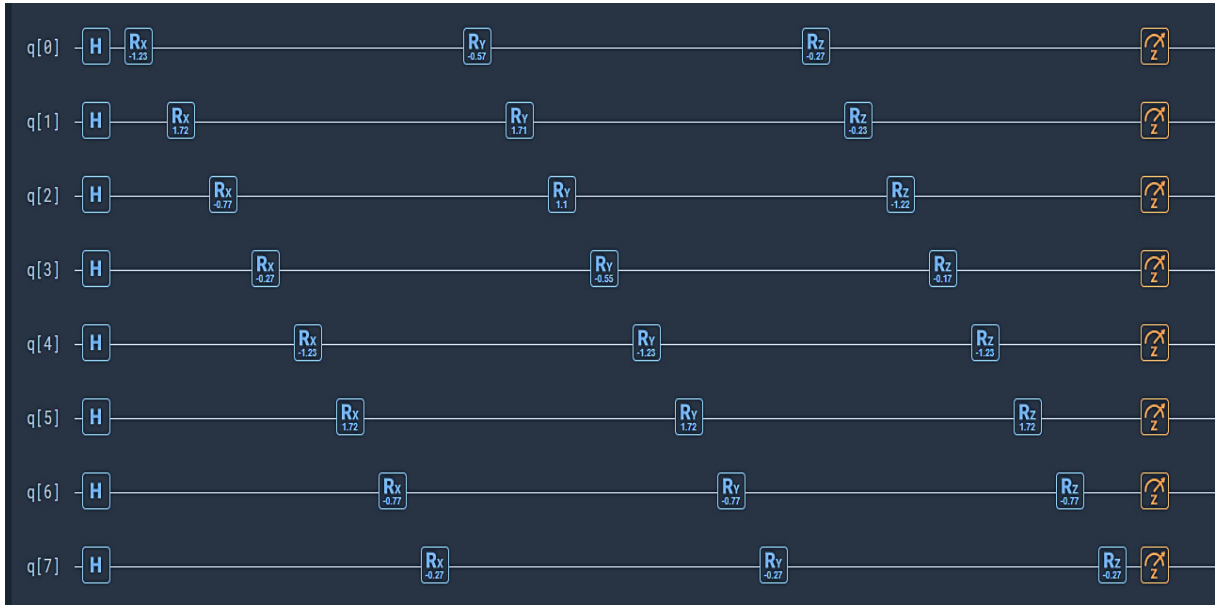


Figure 5. A diagram of a modification of the quantum register.

Source: Own study.

Figure 6 shows a histogram after updating the quantum register using the rotation gates R_x , R_y , R_z .

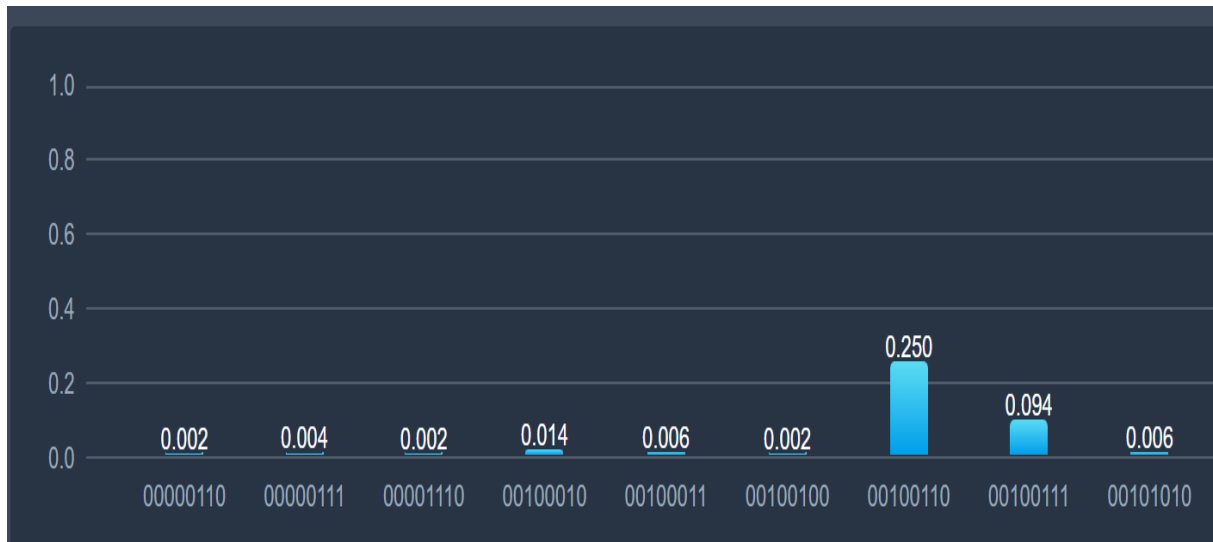


Figure 6. Histogram after updating the quantum register.

Source: Own study.

Because of quantum interference, the probability distribution of the binary chromosomes is a stippled intensity pattern provided by light interference in laser scatter. Consequently, some binary chromosomes are much more likely to occur than others. Digital algorithms for calculating this probability distribution are exponentially more difficult as the number of qubits (width) and number of gate cycles (depth) rise (Balicki, 2023).

6. Concluding Remarks and Future Work

Data fusion based on Convolutional Neural Networks and Long Short-Term Memory Neural Networks can strongly support BPM systems, where the time series of Big Data streams can be reduced to send an edge and core cloud via the Internet of Things. Some intelligent agents in edge computing can significantly support the efficiency of the proposed approach.

The major contributions of this paper are:

- An introduction to the concept that quantum deep transfer learning implemented by the pre-trained Convolutional Neural Networks can filter features of the city image by fusion from sensors to the edge computing layer via the IoT.
- A development of LSTMs for supporting edge computing in the smart city cloud.
- A presentation of some results from the laboratory city cloud simulations.

Our future work will focus on testing other deep neural networks to find efficient predictors and detectors for BPM systems. Besides, quantum-inspired algorithms can also be considered to support big data processing (Beheshti et al., 2023).

References

1. Akan, E. (2023). A holistic analysis of maritime logistics process in fuzzy environment in terms of business process management. *Business Process Management Journal*, 29(16), pp. 1116-1158.
2. Arute, F., Arya, K., Babbush, R. et al. (2019). Quantum supremacy using a programmable superconducting processor. *Nature*, 574, pp. 505-510. Retrieved from: <https://www.nature.com/articles/s41586-019-1666-5>, 15.09.2024.
3. Ayed, B., Halima, A.B., Alimi, A.M. (2015). Big data analytics for logistics and transportation. *4th International Conference on Advanced Logistics and Transport – ICALT*. IEEE, pp. 311-316.
4. Balicka, H. (2020). An influence of deep learning and the internet of things on directions of development of integrated financial systems supporting smart cities for green economy. *Space, Economy, Society*, No. 17/I, pp. 77-102.
5. Balicka, H. (2023). Digital Technologies in the accounting information system supporting decision-making processes. *Scientific Papers of Silesian University of Technology – Organization and Management Series*, No. 169, pp. 57-89.
6. Balicka, H. (2023). The internet of things and deep learning models in the sustainable development of smart cities. *Contemporary Economy*, Vol. 16, Iss. 1(40), pp. 27-43.
7. Balicki, J., Balicka, H., Dryja, P. (2021). Big Data from Sensor Network via Internet of Things to Edge Deep Learning for Smart City. In: K. Saeed, J. Dvorský (eds.), *Computer Information Systems and Industrial Management - CISIM. Lecture Notes in Computer Science*, Vol. 12883. Cham: Springer, pp. 357-368.
8. Balicki, J. (2022). Many-objective quantum-inspired particle swarm optimization algorithm for placement of virtual machines in smart computing cloud. *Entropy*, 24, 58, pp. 1-23.
9. Balicki, J. (2023). Multi-objective quantum-inspired genetic algorithm for supervised learning of deep classification models. In: J. Mikyška, C. de Mulatier, M. Paszyński et al. (eds.), *Computational Science – ICCS 2023. 23rd International Conference, Proceedings, Part V. Lecture Notes in Computer Science*, Vol. 10477. Springer, pp. 246-253.
10. Bartlett, L., Kabir, M.A., Han, J. (2023). A review on Business Process Management system design: The role of virtualization and work design. *IEEE Access*, 11, pp. 116786-116819.
11. Beerepoot, I. et al. (2023). The biggest business process management problems to solve before we die. *Comput. Ind.*, 146, 103837.
12. Beheshti, A., Yang, J., Sheng, Q.Z. et al. (2023). ProcessGPT: Transforming business process management with generative artificial intelligence. *ICWS*, pp. 731-739.

13. Bocciarelli, P., D'Ambrogio, A., Panetti, T. (2023). A Model Based Framework for IoT-aware Business Process Management. *Future Internet*, 15(2), 50.
14. Bozzo-Rey, M., Loredó, R. (2018). *Introduction to the IBM Q experience and quantum computing*. CASCION, pp. 410-412.
15. Chang, V., Chen, Y., Xu, Q.A., Xiong, C. (2023). Evaluation and comparison of various business process management tools. *Int. J. Bus. Inf. Syst.*, 43(3), pp. 281-308.
16. Chen, J., Gan, W., Hu, M., Chen, C.-M. (2020). On the construction of a post-quantum blockchain for smart city. *CoRR abs/2012.15799*.
17. Distel, B., Plattfaut, R., Kregel, I. (2023). How business process management culture supports digital innovation: a quantitative assessment. *Business Process Management Journal*, 29(5), pp. 1352-1385.
18. Dumas, M. et al. (2023). AI-augmented business process management systems: A research manifesto. *ACM Trans. Manag. Inf. Syst.*, 14(1), pp. 1-19.
19. Dunzer, S., Tang, W., Höchstädter, N., Zilker, S., Matzner, M. (2023). *Design principles for using business process management systems*. Business Process Management Workshops, pp. 217-228.
20. Durán, F., Pozas, N., Rocha, C. (2024). Business processes resource management using rewriting logic and deep-learning-based predictive monitoring. *Journal of Logical and Algebraic Methods in Programming*, Vol. 136, 100928.
21. Gadatsch, A. (2023). *Business Process Management - Analysis, modelling, optimisation and controlling of processes*. Springer, ISBN 978-3-658-41583-9.
22. Gajdzik, B., Wolniak, R., Grebski, W. (2024). Challenges of industrial systems in terms of the crucial role of humans in the Industry 5.0 environment. *Production Engineering Archives*, Vol. 30, Iss., pp. 1-30.
23. Gajdzik, B., Wolniak, R., Grebski, W. et al. (2024). *Sustainability and smart manufacturing the transformation of the steelwork industry*. New York: Routledge. ISBN 978-1-032-69737-6.
24. Gajdzik, B., Wolniak, R., Grebski, W. et al. (2024). *Smart cities with smart energy systems. Key development directions*. Gliwice: Silesian University of Technology Press, ISBN 978-83-7880-939-5.
25. Hassan A. et al. (2024). *Quantum Computing and Supply Chain Management: A New Era of Optimization*. New York: IGI Global Scientific Publishing.
26. Ji, S., Xu, W., Yang, M., Yu, K. (2013). 3D Convolutional neural networks for human action recognition. *IEEE Trans. Pattern Anal. Mach. Intell.*, 35, pp. 221-231.
27. Krizhevsky, A., Sutskever, I., Hinton, G.E. (2012). ImageNet classification with deep convolutional neural networks. *Adv. Neural Inf. Process. Syst.*, 25, pp. 1097-1105.
28. Kuehne, H., Jhuang, H., Garrote, E., Poggio, T., Serre, T. (2011). *HMDB: A large video database for human motion recognition*. Proceedings of the International Conference on Computer Vision. Barcelona, Spain: IEEE, pp. 2556-2563.

29. Lecun, Y., Bengio, Y., Hinton, G. (2015). Deep learning. *Nature*, 521, pp. 436-444.
30. Lei, Y., Jia, F., Lin, J., Xing, S. (2016). An intelligent fault diagnosis method using unsupervised feature learning towards mechanical Big Data. *IEEE Trans. Ind. Electron.*, 63, pp. 3137-3147.
31. Li, H.X., Chosler, R. (2007). *Application of multilayered multi-agent data mining architecture to bank domain*. International Proceedings on Wireless Communications and Mobile Computing, pp. 6721-6724.
32. Li, L., Wu, Y., Ou, Y., Li, Q., Zhou, Y., Chen, D. (2018). *Research on machine learning algorithms and feature extraction for time series*. IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC, pp. 1-5.
33. Lotko, A. (2005). Classifications of IT projects in the context of their effectiveness. *Organizational Review*, No. 1, pp. 38-40 (in Polish).
34. Lotko, A. (2005). Modeling information technology effectiveness. *Operations Research and Decisions*, Wroclaw University of Science and Technology, Faculty of Management, Vol. 15(1), pp. 43-52.
35. Lotko, A. (2018). Using Neural Networks in Modeling Customer Loyalty in Passenger Cars Maintenance and Repair Services. *Applied Sciences*, 8(5), 713.
36. Lotko, A. (2022). The Influence of the Quality of Internet Banking Services on Customer Loyalty. *European Research Studies Journal*, Vol. XXV, Iss. 2B, pp. 259-276.
37. Marz, N., Warren, J. (2014). *Big data – principles and best practices of scalable realtime data systems*. Shelter Island: Manning.
38. O'Leary, D.E. (2013). Artificial Intelligence and Big Data. *IEEE Intelligent Systems*, 28(2), pp. 96-99.
39. Ravi, L., Subramaniaswamy, V., Varadharajan, V., Gao, X.-Z., Indragandhi, V. (2018). A hybrid quantum-induced swarm intelligence clustering for the urban trip recommendation in smart city. *Future Gener. Comput. Syst.*, 83, pp. 653-673.
40. Saif, M.A.N., Aradhya, S.K.N., Murshed, B.A.H., Alnaggar, O.A.M.F., Ali, I.M.S. (2023). Multi-objective container scheduling and multi-path routing for elastic business process management in autonomic multi-tenant cloud. *Concurr. Comput. Pract. Exp.*, 35(6), p. 1.
41. Schmidhuber, J. (2014). Deep learning in neural networks. An overview. *Neural Netw.*, 61, pp. 85-117.
42. Taherdoost, H., Madanchian, M. (2024). Blockchain and Business Process Management (BPM) synergy (2024). A comparative analysis of modeling approaches. *Inf.*, 15(1), p. 9.
43. Tian, X., Pavur, R., Han, H., Zhang, L. (2023). A machine learning-based human resources recruitment system for business process management: using LSA. *BERT and SVM. Bus. Process. Manag. J.*, 29(1), pp. 202-222.
44. Węglarz, J., Błazewicz, J., Kovalyov, M. (2006). Preemptable malleable task scheduling problem. *IEEE Transactions on Computers*, 55(4), pp. 486-490.

45. Wolniak, R. (2023). Innovations in industry 4.0 conditions. *Scientific Papers of Silesian University of Technology – Organization and Management Series*, No. 169, pp. 725-741.
46. Wolniak, R. (2023). The concept of descriptive analytics. *Scientific Papers of Silesian University of Technology – Organization and Management Series*, No. 172, pp. 699-715.
47. Wolniak, R. (2024). Continuous improvement: leveraging business analytics in Industry 4.0 settings. *Scientific Papers of Silesian University of Technology – Organization and Management Series*, No. 203, pp. 599-616.
48. Wolniak, R., Stecuła, K. (2024). Artificial Intelligence in Smart Cities - Applications, Barriers, and Future Directions: A Review. *Smart Cities*, Vol. 7, No. 3, pp.1346-1389.
49. Zhao, R., Yan, R., Wang, J., Mao, K. (2017). Learning to monitor machine health with convolutional bi-directional LSTM networks. *Sensors*, 17, p. 273.
50. Zhou, D. et al. (2010). *Multi-agent distributed data mining model based on algorithm analysis and task prediction*. International Proceedings on Information Engineering and Computer Science, pp. 1-4.

DIFFERENCES IN INTERTEMPORAL PREFERENCES FOR MONEY AND ENVIRONMENTAL GOODS: THE CASE OF POLAND

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Purpose: The main scientific purpose of the paper is twofold. At first, the author aims to determine whether there exist any significant differences between intertemporal preferences of Polish citizens for money and environmental goods as measured by elicited individual discount rates. Additionally, the purpose of the paper is to reveal the socio-economic and demographic factors influencing the abovementioned intertemporal preferences.

Design/methodology/approach: The data about individual intertemporal preferences and socio-economic and demographic characteristics were collected via an online survey. To determine the respondents' willingness to pay and their individual discount rates the stated approach was used – the conditional valuation (CV) method. In the analysis of statistical properties of data collected various statistical methods were used. The differences between estimated discount rates were investigated by employing ANOVA methods, while the influence of socio-economic and demographic factors on their level was assessed by building and estimating a multiple regression model.

Findings: The main outcome of the paper is proving that the individual discount rates decline when the time frame considered is lengthened. At the same time, it has been revealed, that there exist significant differences between elicited discount rates for various types of goods analyzed – the lowest one for public environmental goods, while the highest one for private monetary benefits.

Research limitations/implications: One of the limitations of the study is the disadvantage of the Multiple Price List method employed resulting in a limited number of possible discount rates elicited. Even though the respondents could have given any other value they wished, this possibility was rarely used.

Practical and social implications: The estimated individual discount rates for various types of goods provide information about societal preferences regarding intertemporal choices. The outcomes of the study can be used to evaluate the efficiency of public policies regarding environmental protection, energy transformation, etc.

Originality/value: The studies analyzing the level of individual discount rates for various types of goods (especially environmental ones) in the case of Poland are quite rare and of limited number of respondents involved. In this study not only their levels for different goods (monetary vs environmental, private vs public) are compared, but also factors influencing them are considered and revealed. Moreover, while analyzing the willingness to pay for the abovementioned types of goods, the fact that the respondent is an inhabitant of the GZM

Metropolis or not is also considered to provide information about differences in intertemporal preferences between the residents of mining regions and others.

Keywords: intertemporal preferences; discount rate; money; environmental goods; mining regions.

Category of the paper: research paper.

1. Introduction

One of the most important challenges nowadays, as described by the Sustainable Development Goals of the United Nations, is taking action to combat climate change and its consequences while ensuring affordable, reliable, sustainable and modern energy for all (United Nations, 2015). All these efforts require additional investments transforming economies into green and circular ones. Among the countries facing significant challenges in this field is Poland. Despite the efforts to diminish the level of greenhouse gas emissions over past years (Bórawski et al., 2022) (Figure 1) and share of fossil fuels in electricity generation, total energy supply (Figure 2) and total final production (still the highest one among all members of the International Energy Agency in 2020) (International Energy Agency, 2022), the challenges posed by the European Green Deal and Fit for 55 plan focused on EU's target of reducing net greenhouse gas emissions by at least 55% by 2030 are quite demanding.

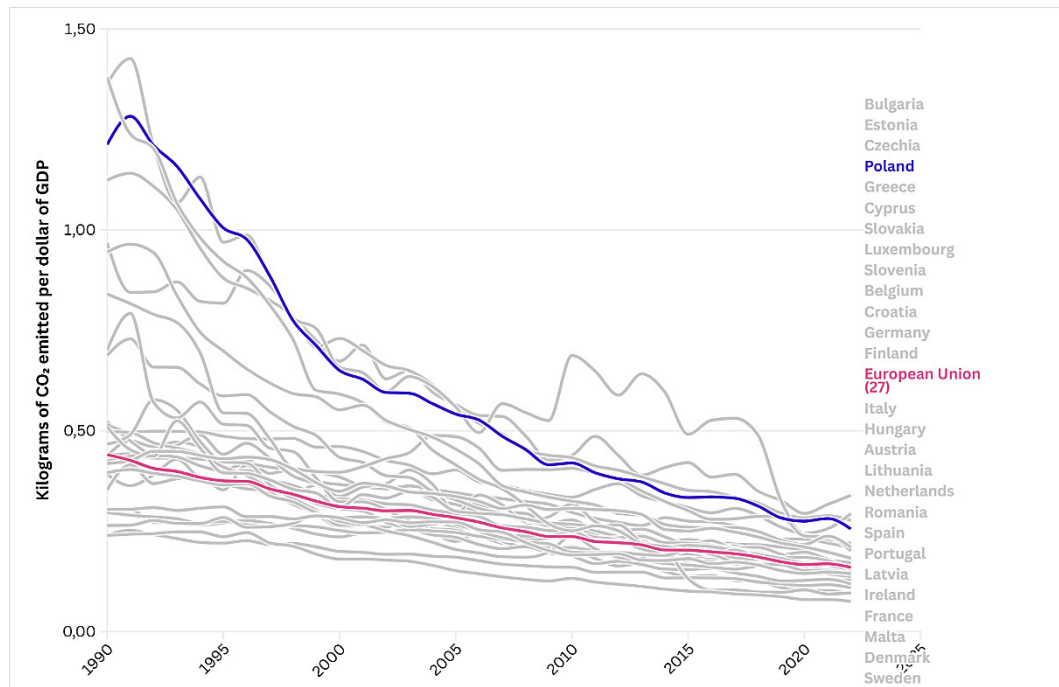


Figure 1. CO₂ emissions per GDP (in USD).

Source: Own elaboration based on (Our World in Data, 2024).

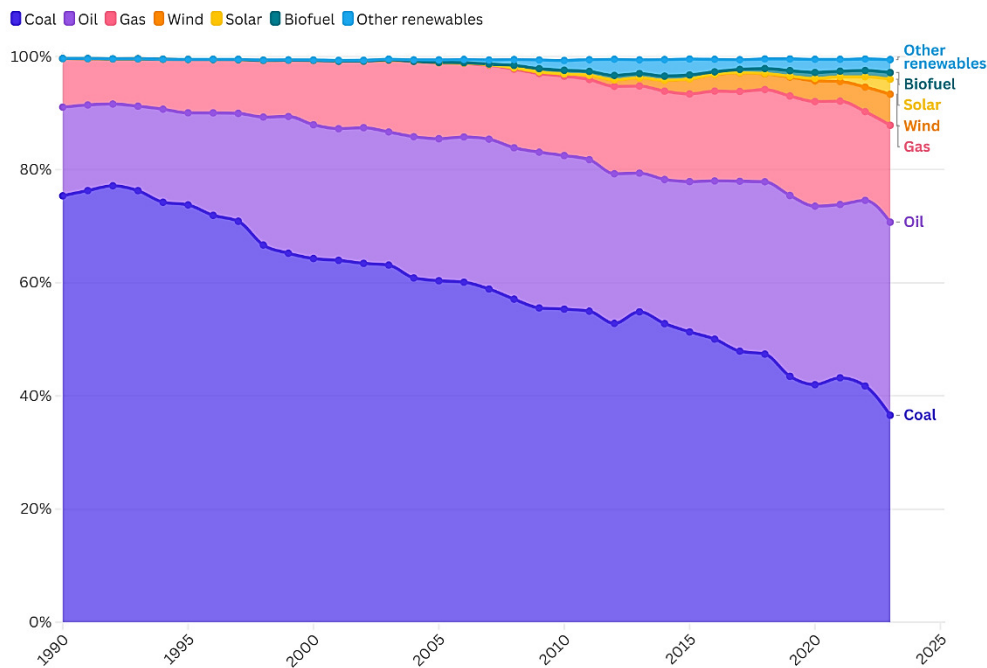


Figure 2. Evolution of the total energy supply structure for Poland.

Source: Own elaboration based on (Our World in Data, 2024).

A crucial parameter in making decisions to invest due to different time profiles of costs and benefits is the discount rate. Taking into account the high sensitivity of the outcomes of the investment project evaluation to changes in the discount rate, it can be observed that it plays a crucial role in making decisions related to energy transformation, as these decisions have long-term impacts. As not all the costs and benefits can be easily measured in monetary terms due to non-marketability, a widely used method is the so-called contingent valuation (CV), an approach based on the stated preferences of the respondents regarding their willingness to pay for future changes in the consumption level of a specific good. Nevertheless, it is not an easy task to determine its pattern (e.g. constant vs declining) and level. The main aim of this study is to determine the level of individual discount rates for three types of goods: private monetary benefits, public monetary benefits and public environmental benefits. The hypothesis regarding their level can be formulated as follows:

H1: The discount rate for private monetary benefits is the highest one, while the discount rate for public environmental goods is the lowest one.

Moreover, as proved by many studies, e.g. (Buła, Foltyn-Zarychta, 2022) the level of discount rate should not be taken as constant, but due to variability in consumption patterns or divergence of the opinions of society members, should decline over time. Thus, the second hypothesis claims, that:

H2: The discount rates for all types of goods considered decline with lengthening of the time horizon considered.

In the next section the methods used to verify the abovementioned hypotheses as well as the material are described.

2. Material and methods

Elicitation of individual discount rates can be based on data gathered in various ways, e.g. online surveys, natural experiments, etc. To obtain a sufficiently large and, at the same time, representative dataset an online survey was conducted. The questionnaire prepared was distributed within one month (1-31 August 2024) by a professional company among adult inhabitants of the Republic of Poland and, consequently, 2000 responses were collected. To make the data collected representative the quota sampling method was employed. As a result, the analyzed dataset is representative if the place of living (voivodship), gender and age are considered.

The questionnaire was divided into a few parts. In the first one, the respondents were informed about the aim of the survey (analysis of attitudes towards environmental protection) and asked to share their opinions. In the next part, they were asked about basic demographic attributes as well as socio-economic status (gender, age, education level, number of household members, having children below 18 years of age, place of living including county and voivodship). In the following one, the participants were confronted with three hypothetical situations. In the first one, they were informed about winning 100 PLN in a lottery (private monetary benefit). The main assumption describing the second one was that the Ministry of Climate and Environment receives an additional amount of money (100 m PLN) to increase the area of national parks in Poland and enable more citizens to visit them without altering the biosphere (public monetary benefit). In the third scenario, they were informed that Białowieża National Park's area is going to be increased by 100 ha (public environmental benefit). Then, the respondents were asked a contingent valuation question, formulated as "What reward in the future would induce you to resign from the immediate reward of 100?" (separately in all three scenarios). Among different options used to reveal the respondents' willingness to pay, the Matrix Multiple Price List of (Richards, Green, 2015) was applied (the MMPL employed is presented in Table 1).

Table 1.*Matrix Multiple Price List used in the survey*

Payment							
Imme- diately	After 1 year	After 5 years	After 10 years	After 30 years	After 50 years	After 70 years	After 100 years
100	100	100	100	100	100	100	100
100	101	104	105	108	108	109	111
100	102	108	110	116	116	119	122
100	105	120	128	145	145	155	165
100	110	144	163	210	210	238	270
100	115	170	206	302	304	368	444
100	125	236	324	615	630	860	1 180
100	140	372	620	1 740	1 840	3 040	5 050
100	160	640	1 380	6 600	7 450	15 800	34 000
100	180	1 050	2 900	23 800	29 000	79 000	220 000
100	200	1 640	5 750	81 000	108 000	380 000	1 380 000
100	other	other	other	other	other	other	other

Source: Own elaboration.

One of the problems encountered while asking the contingent valuation question is the lack of trust expressed by the respondents. Simply since they do not believe that the experimenter will remit payment at a future date (the “front-end-delay effect”), they heavily prefer short periods as within a short period the payment seems to be more probable. To avoid this obstacle, the respondents were informed that all the payments would be delayed by one month due to bureaucratic requirements to be fulfilled, following the idea of (Andersen et al., 2008).

In the next part of the questionnaire respondents’ attitudes towards environmental protection as well as their values, beliefs and norms are measured using the NEP and the Value-Belief-Norm model scales (Dunlap, Van Liere, 1978; Stern, 2000; Stern et al., 1999). Moreover, the participants’ trust in public authorities at different levels (local, municipal, state) is measured as well as their knowledge about national parks and environmental protection in Poland.

The last section of the survey is devoted to the investigation of economic issues, i.e. level of net income, loans, savings and perceived creditworthiness of respondents. It is aimed at measuring the socio-economic status of participants, like in the first part various demographic characteristics were included.

The socio-economic and demographic profile of the respondents is presented in Table 2. The dataset is representative while taking into account place of living (voivodship), gender and age. The geographical distribution of respondents is shown in Figure 3.

Table 2.
Demographic and socio-economic profile of respondents

Variable	Options	Share - survey	Share - Poland
Gender	Female	52.25%	51.64%
	Male	47.75%	48.31%
Age	18-29	14.95%	15.23%
	30-39	18.00%	17.96%
	40-49	19.85%	19.52%
	50-59	15.05%	14.96%
	60 and more	32.15%	32.33%
Education	Primary school	1.05%	5.70%
	Vocational school	9.45%	
	Middle school	0.60%	
	High school	31.05%	56.4%
	Post-secondary school	11.70%	
	Bachelor's degree	9.35%	37.9%
	Master's degree or higher	36.80%	
Household size	1	14.40%	22.57%
	2	29.70%	25.06%
	3	26.60%	19.04%
	4	19.50%	16.33%
	5	6.25%	17.01%
	6	2.50%	
	7	0.75%	
	8 and more	0.30%	
Children under 18	Yes	36.00%	37.55%
	No	64.00%	62.45%
Living place	Rural	26.60%	40.55%
	Urban	73.40%	59.45%
Net income (monthly)	Up to 1500 PLN	5.35%	-
	1501-3000 PLN	15.75%	
	3001-4500 PLN	29.25%	
	4501-6000 PLN	22.65%	
	6001-7500 PLN	9.80%	
	7501 PLN and more	7.90%	
	Do not want to answer	9.30%	
Credit/loan	Yes	27.05%	47.90%
	No	72.95%	52.10%
Savings/investments	Yes	47.35%	55.00%
	No	52.65%	45.00%
Creditworthiness (declared)	Yes	60.30%	-
	No	39.70%	

Data for Poland as of 2023 except for household size and children under 18 (Census 2021), credit/loan and savings/investment (2024).

Source: Own elaboration and (Bankier.pl, 2024; BIK, 2024; GUS, 2023).

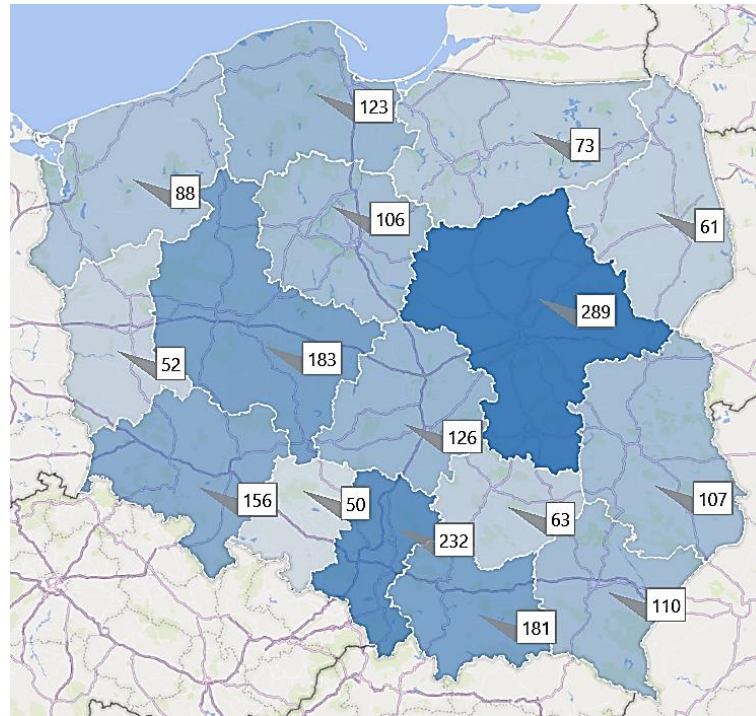


Figure 3. Number of respondents from each voivodship.

Source: Own elaboration.

The demographic and socio-economic profile of the respondents is quite similar to the entire Polish society with some discrepancies regarding education level, living place (rural vs urban) and financial situation. However, the abovementioned differences do not seem to be severely influencing the conclusions presented in the following sections.

As the respondents were not asked directly about their discount rate, but rather their willingness to pay, the individual discount rates were calculated (as logarithmic ones):

$$R = \frac{1}{n} \ln \left(\frac{WTP}{100} \right) \quad (1)$$

where:

n – time horizon in years,

$n = 1, 5, 10, 30, 50, 70, 100$,

WTP – declared compensation required. This transformation performs better than if the discount rate is calculated as an average, simple required rate of return or even the geometric one, reducing the number of outliers (the Grubbs' statistic decreases significantly).

In this paper two methods of statistical analysis were used: the standard multiple regression model and the ANOVA method. The analysis of variance was used to predetermine the possible influence of single factors on the level of elicited individual discount rates and to verify the hypothesis that discount rates are equal for different goods and various time horizons. The influence of demographic and socio-economic factors on the level of individual discount rates was investigated by estimating a linear multiple regression model for every type of good and compensation delay:

$$\begin{aligned}
R = & \beta_0 + \beta_1 \cdot \text{Gender} + \beta_2 \cdot \text{Age} + \beta_3 \cdot \text{Education} + \beta_4 \cdot \text{Household size} + \\
& + \beta_5 \cdot \text{Children under 18} + \beta_6 \cdot \text{Living place} + \beta_7 \cdot \text{GZM Metropolis} + \\
& + \beta_8 \cdot \text{Net income} + \beta_9 \cdot \text{Credit|Loan} + \beta_{10} \cdot \text{Savings|investment} + \\
& + \beta_{11} \cdot \text{Creditworthiness} + \xi
\end{aligned} \tag{2}$$

where the variables: Gender (male – 0, female – 1), Education (high school or lower – 0, post-secondary school or higher – 1), Children under 18 (no – 0, yes – 1), Living place (rural – 0, urban – 1), GZM Metropolis (if a respondent is not an inhabitant of GZM Metropolis – 0, otherwise – 1), Credit/loan (no – 0, yes – 1), Savings/investment (no – 0, yes – 1), Creditworthiness (no – 0, yes – 1) are binary variables.

The ANOVA analysis was conducted as an analysis of a series of repeated measurements, as the respondents were asked about the level of their willingness to pay for a wide variety of time horizons and types of goods. As the final check, the post hoc Bonferroni test was used to compare the differences between measurements. The results are delineated in the next section.

3. Results and discussion

In the first step, the level of elicited discount rates (Figure 4) was compared and tested using the ANOVA method. The detailed statistical description of elicited discount rates is presented in Table 3.

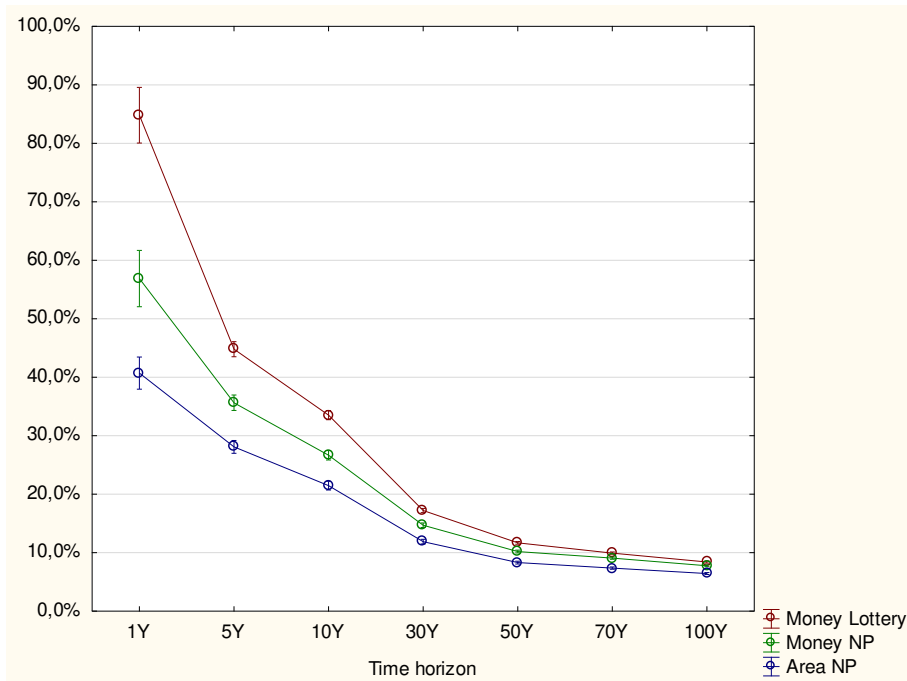


Figure 4. The averages of elicited discount rates with errors.

Source: Own elaboration.

Table 3.*Statistical characteristics of the elicited individual discount rates*

Type of good & delay	Average $\pm$ Error	Median	Mode	Min	Max	St. dev.	CV
Money lottery 1Y	84.8% $\pm$ 2.4%	69.3%	69.3%	0.0%	990.3%	108.5%	127,9
Money lottery 5Y	44.8% $\pm$ 0.7%	47.0%	55.9%	0.0%	216.4%	29.3%	65,3
Money lottery 10Y	33.5% $\pm$ 0.4%	40.5%	40.5%	0.0%	115.1%	17.8%	53,1
Money lottery 30Y	17.2% $\pm$ 0.2%	19.0%	22.3%	0.0%	61.4%	8.1%	47,3
Money lottery 50Y	11.7% $\pm$ 0.1%	14.0%	14.0%	0.0%	46.1%	5.3%	45,1
Money lottery 70Y	9.9% $\pm$ 0.1%	11.8%	11.8%	0.0%	42.8%	4.4%	44,8
Money lottery 100Y	8.4% $\pm$ 0.1%	9.5%	9.5%	0.0%	115.1%	4.5%	53,1
Money NP 1Y	56.9% $\pm$ 2.5%	58.8%	69.3%	0.0%	1450.9%	109.8%	193,0
Money NP 5Y	35.6% $\pm$ 0.7%	37.1%	55.9%	0.0%	322.4%	30.2%	84,6
Money NP 10Y	26.7% $\pm$ 0.4%	26.2%	40.5%	0.0%	177.3%	18.4%	69,0
Money NP 30Y	14.7% $\pm$ 0.2%	18.2%	22.3%	0.0%	62.0%	8.9%	60,3
Money NP 50Y	10.2% $\pm$ 0.1%	11.3%	14.0%	0.0%	41.4%	5.4%	52,7
Money NP 70Y	9.1% $\pm$ 0.1%	11.8%	11.8%	0.0%	49.3%	4.4%	48,5
Money NP 100Y	7.8% $\pm$ 0.1%	9.5%	9.5%	0.0%	39.1%	3.6%	46,1
Area NP 1Y	40.7% $\pm$ 1.4%	33.6%	69.3%	0.0%	1371.0%	62.8%	154,2
Area NP 5Y	28.1% $\pm$ 0.6%	26.3%	55.9%	0.0%	274.2%	25.0%	89,0
Area NP 10Y	21.5% $\pm$ 0.4%	18.2%	40.5%	0.0%	207.2%	17.1%	79,6
Area NP 30Y	11.9% $\pm$ 0.2%	9.5%	22.3%	0.0%	92.1%	8.9%	75,0
Area NP 50Y	8.3% $\pm$ 0.1%	8.6%	14.0%	0.0%	64.5%	5.5%	66,6
Area NP 70Y	7.4% $\pm$ 0.1%	9.5%	11.8%	0.0%	52.6%	4.6%	62,7
Area NP 100Y	6.4% $\pm$ 0.1%	7.7%	9.5%	0.0%	41.4%	3.7%	58,3

NP – National Park.

Source: Own elaboration.

The first conclusion to be drawn upon the abovementioned results is the fact the level of elicited discount rates is steadily decreasing (at a slower pace, but that seems to be quite natural as the compensation to be declared is bounded from below, and as a result, the discount rates cannot be negative). The remarkable differences in the averages and low standard errors suggest the existence of statistically significant differences between elicited discount rates. The hypothesis that they are equal across various time horizons and types of goods was tested using the ANOVA method (repeated measures as the declared willingness to pay values were declared by the same respondents) and the post-hoc Bonferroni test to investigate which particular differences are significantly different. The results of the analysis are presented in Table 4.

Table 4.*The results of the ANOVA analysis (repeated measures) and Bonferroni posthoc test for the elicited individual discount rates*

Time horizon	1Y		5Y		10Y		30Y		50Y		70Y		100Y
Money Lottery	84.8%	>	44.8%	>	33.5%	>	17.2%	>	11.7%	~	9.9%	~	8.4%
	✓		✓		✓		✓		✓		✓		✓
Money NP	56.9%	>	35.6%	>	26.7%	>	14.7%	>	10.2%	~	9.1%	~	7.8%
	✓		✓		✓		✓		✓		✓		✓
Area NP	40.7%	>	28.1%	>	21.5%	>	11.9%	>	8.3%	~	7.4%	~	6.4%

NP – National Park.

Source: Own elaboration.

The results of the ANOVA analysis with the post-hoc Bonferroni test confirm the main earlier predictions. The differences between discount rates for time horizons from 1 year up to 50 years show significant variability of the elicited discount rates and their diminishing character. This supports the hypothesis that lengthening the time horizon should lead to the application of the concept of the declining discount rate, DDR (Gollier, Weitzman, 2010; Lowe, 2008; Weitzman, 1998, 2001). This study provides a clear confirmation that the DDR concept can be applied to various types of goods, including environmental ones. This trend is maintained even when the time horizons over 50 years are considered, but due to variability of the elicited discount rates the Bonferroni test does not allow to reject the hypothesis of their equality.

Performing a similar analysis but now considering the type of good as the main interfering factor provides a clear justification for the assumption that the level of discount rate applied should be different for distinct goods. The elicited discount rates are unequivocally lowest for the enlargement of the national parks (public environmental good) and highest for private monetary benefits. This relationship is valid for all time horizons considered.

To analyze the influence of the demographic and socio-economic factors on implied discount rates, a multiple regression analysis was performed. The results are summarized in Tables 5-7.

Table 5.

The results of multiple regression for private monetary benefits

Delay	1Y	5Y	10Y	30Y	50Y	70Y	100Y
Intercept	1.1363	0.5417	0.3970	0.1887	0.1236	0.1028	0.0882
Gender	0.1803	0.0429	0.0250	0.0077	0.0025	0.0010	- 0.0009
Age	- 0.0081	- 0.0030	- 0.0019	- 0.0007	- 0.0004	- 0.0002	- 0.0003
Education	0.1247	0.0498	0.0315	0.0146	0.0083	0.0068	0.0041
Household size	- 0.0684	- 0.0129	- 0.0079	- 0.0025	- 0.0020	- 0.0016	0.0003
Children (under 18)	0.0594	- 0.0076	- 0.0088	- 0.0014	0.0015	0.0014	- 0.0021
Living place	0.0711	0.0072	0.0046	0.0022	0.0021	0.0009	0.0037
GZM Metropolis	- 0.0920	0.0181	0.0121	0.0027	- 0.0000	0.0007	0.0011
Net income	- 0.0624	- 0.0003	0.0015	0.0042	0.0022	0.0029	0.0003
Credit/Loan	0.1166	0.0308	0.0184	0.0063	0.0024	0.0019	- 0.0006
Savings/investment	- 0.0170	0.0008	- 0.0042	0.0006	0.0023	0.0023	0.0014
Creditworthiness	0.0303	0.0164	0.0183	0.0085	0.0072	0.0060	0.0030
R ²	0.0313	0.0395	0.0433	0.0348	0.0301	0.0265	0.0129
Adjusted R ²	0.0253	0.0337	0.0375	0.0290	0.0242	0.0205	0.0068
F	5.29	6.74	7.42	5.91	5.09	4.45	2.13
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0156

Source: Own elaboration.

Table 6.

The results of multiple regression for public monetary good

Delay	1Y	5Y	10Y	30Y	50Y	70Y	100Y
Intercept	0.4689	0.3558	0.2686	0.1506	0.0989	0.0859	0.0692
Gender	0.1421	0.0500	0.0268	0.0107	0.0050	0.0028	0.0014
Age	- 0.0017	- 0.0014	- 0.0009	- 0.0004	- 0.0001	- 0.0000	0.0001
Education	0.0042	0.0067	0.0155	0.0076	0.0066	0.0029	0.0029
Household size	0.0115	0.0022	- 0.0006	- 0.0020	- 0.0008	- 0.0005	- 0.0001
Children (below 18)	- 0.0454	- 0.0057	- 0.0085	- 0.0026	- 0.0023	- 0.0008	0.0004

Cont. table 6.

Living place	0.0822	0.0213	0.0130	0.0041	0.0005	- 0.0012	- 0.0016
GZM Metropolis	0.1116	0.0261	0.0156	0.0077	0.0042	0.0001	0.0001
Net income	0.0363	0.0206	0.0096	0.0074	0.0056	0.0048	0.0037
Credit/Loan	0.0285	0.0015	0.0009	0.0014	0.0011	0.0010	0.0016
Savings/investment	- 0.0358	- 0.0082	- 0.0028	0.0009	0.0012	0.0023	0.0021
Creditworthiness	- 0.0123	0.0072	0.0081	0.0048	0.0028	0.0031	0.0026
R ²	0.0089	0.0132	0.0142	0.0135	0.0128	0.0092	0.0106
Adjusted R ²	0.0028	0.0071	0.0082	0.0075	0.0068	0.0031	0.0046
F	1.47	2.19	2.35	2.25	2.12	1.51	1.76
p-value	0.1369	0.0130	0.0070	0.0104	0.0162	0.1195	0.0555

Source: Own elaboration.

Table 7.*The results of multiple regression for public environmental good*

Delay	1Y	5Y	10Y	30Y	50Y	70Y	100Y
Intercept	0.4237	0.3070	0.2381	0.1271	0.0879	0.0741	0.0651
Gender	0.0904	0.0542	0.0328	0.0158	0.0096	0.0078	0.0054
Age	- 0.0012	- 0.0013	- 0.0009	- 0.0004	- 0.0003	- 0.0001	- 0.0001
Education	0.0668	0.0100	0.0054	0.0012	0.0018	0.0020	0.0009
Household size	- 0.0162	- 0.0035	- 0.0046	- 0.0025	- 0.0014	- 0.0010	- 0.0008
Children (below 18)	0.0033	0.0025	0.0133	0.0073	0.0060	0.0045	0.0039
Living place	0.0379	0.0048	0.0000	0.0014	- 0.0000	0.0003	- 0.0002
GZM Metropolis	- 0.0161	0.0057	0.0011	- 0.0010	0.0014	0.0001	- 0.0020
Net income	- 0.0006	0.0197	0.0247	0.0109	0.0053	0.0042	0.0032
Credit/Loan	- 0.0002	- 0.0006	0.0001	0.0031	0.0005	0.0010	0.0014
Savings/investment	- 0.0450	- 0.0008	- 0.0010	0.0004	0.0012	0.0012	0.0005
Creditworthiness	- 0.0232	- 0.0042	0.0012	0.0012	0.0001	- 0.0000	- 0.0005
R ²	0.0132	0.0177	0.0191	0.0161	0.0163	0.0142	0.0111
Adjusted R ²	0.0072	0.0117	0.0131	0.0101	0.0103	0.0082	0.0050
F	2.19	2.95	3.19	2.68	2.72	2.35	1.83
p-value	0.0127	0.0007	0.0003	0.0020	0.0017	0.0070	0.0443

Source: Own elaboration.

The results presented lead to the formulation of a conclusion that the two most important factors shaping the level of elicited discount rates are gender and age. Generally, women declared higher interest rates, but this influence was long-term only in case of the public environmental goods. In other cases, it disappeared when considering time horizons longer than 30 years. On the other hand, age diminishes the discount rate for all periods analyzed (with exception for extremely long-term periods in the case of public goods).

It is also visible that discount rates appropriate for private monetary benefits are also rising with the education level of the respondents and the household size (but only for short-term rates, 1-5 years). Higher rates are also declared when the respondent is a borrower (for time horizons up to 10 years), or is convinced that he could borrow an additional amount of money (time horizons between 10 and 70 years). Thus, a set of demographic and socio-economic factors influencing the time preferences of Polish citizens is rather narrow – it includes gender and age, and partially by the education level, household size and being a borrower.

4. Summary and conclusions

In the paper, the time preference of a large sample of Polish citizens was investigated by eliciting and analyzing the individual discount rates. Three different types of goods were analyzed: private monetary benefits, public monetary benefits and public environmental ones. The main conclusions of the study are twofold. First, it has been shown that the individual discount rates decline when lengthening time horizons is considered (and the decline is considerable). These observations lead to the conclusion that the common assumption of the constant discount rate used to evaluate various types of investment projects, including environmental and related to the energy transformation process, should be assessed using the concept of DDR (declining discount rate) as suggested, e.g., by (Buła, Foltyn-Zarychta, 2022).

Table 8

The results of chosen studies devoted to eliciting discount rates for money and other goods

Study	(Cropper et al., 1994)		(Meerding et al., 2010)		(Newell, Siikamaki, 2015)		(Atmadja et al., 2017)		(Green, Richards, 2018)		(Foltyn-Zarychta, 2020)		Current study	
R_{money} VS $R_{\text{environment}}$			=						>		>		>	
Sample	3000 households		207 individuals		1217 households		10,000 households		93 individuals		502 individuals		2000 individuals	
Country	USA		Netherlands		USA		India		USA		Poland		Poland	
Good	M	E	M	H	M	E	M	E/H	M	E	M	E	M	E
Gender		↓	=	↑		↑		↑*	↓*	↓	↓*	↑	↓*	↓*
Age		↑*	↑*	↑*		↑		↓	↓	↑*	↓*	↓*	↓*	↓*
Education		↑	↑*	↑		↓*					↑*	↓*	↑*	↑
Household size						↑*	↑				↑*	↑*	↓*	↓
Children (below 18)		↑*	↑*	↑		?					↓*	↓	?	↑
Living place													↑	?
GZM Metropolis													?	?
Net income		↓	↑	↑*		↓?		↓			↑	↑	?	↑
Credit/Loan													↑*	?
Savings/investment													?	?
Creditworthiness						↓?		↓*					↑*	?

R_{money} – discount rate for money; $R_{\text{environment}}$ – discount rate for environmental goods; M – money; E – environmental goods; H – health; Gender (male – 0, female – 1), Education (high school or lower – 0, post-secondary school or higher – 1), Children under 18 (no – 0, yes – 1), Living place (rural – 0, urban – 1), GZM Metropolis (not an inhabitant of GZM Metropolis – 0, otherwise – 1), Credit/loan (no – 0, yes – 1), Savings/investment (no – 0, yes – 1), Creditworthiness (no – 0, yes – 1); * – statistically different from 0.

Source: Own elaboration.

Second, it has been proved that among various demographic and socio-economic factors affecting the elicited discount rates two are most influential: age and gender (Table 8). Men and the elder tend to declare lower discount rates. However, the analysis of the results of recent studies devoted to this problem does not provide us with clear answers, as the results are often mixed or dependent on the time horizon considered. Moreover, it must be emphasized

that the dominant part of individual discount rate variability is not explained by the abovementioned factors, but rather should be assigned to other, individual-specific features, which is the main limitation of this study, but also creates a chance to extend this analysis to include respondents' values and beliefs as explanatory variables.

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References

1. Andersen, S., Harrison, G., Lau, M., Rutstrom, E. (2008). Eliciting Risk and Time Preferences. *Econometrica*, 76(3), 583-618.
2. Atmadja, S.S., Sills, E.O., Pattanayak, S.K., Yang, J.-C., Patil, S. (2017). Explaining environmental health behaviors: Evidence from rural India on the influence of discount rates. *Environment and Development Economics*, 22(3), 229-248.
3. Bankier.pl (2024). *Bankier.pl*. <https://www.bankier.pl/>
4. BIK (2024). *Biuro Informacji Kredytowej*. <https://www.bik.pl/>
5. Bórawski, P., Beldycka-Bórawska, A., Holden, L., Rokicki, T. (2022). The Role of Renewable Energy Sources in Electricity Production in Poland and the Background of Energy Policy of the European Union at the Beginning of the COVID-19 Crisis. *Energies*, 15(22), 8771.
6. Buła, R., Foltyn-Zarychta, M. (2022). Declining Discount Rates for Energy Policy Investments in CEE EU Member Countries. *Energies*, 16(1), 321.
7. Cropper, M.L., Aydede, S.K., Portney, P.R. (1994). Preferences for life saving programs: How the public discounts time and age. *Journal of Risk and Uncertainty*, 8, 243-265.
8. Dunlap, R.E., Van Liere, K.D. (1978). The "New Environmental Paradigm". *The Journal of Environmental Education*, 9(4), 10-19. <https://doi.org/10.1080/00958964.1978.10801875>
9. Foltyn-Zarychta, M. (2020). The Dilemmas of Public vs. Private Goods Discounting for Long-Term Investment Appraisal: The Puzzle of Citizen and Consumer Approaches to Valuation. *Folia Oeconomica Stetinensia*, 20(2), 114-133.

10. Gollier, C., Weitzman, M. (2010). How should the distant future be discounted when discount rates are uncertain? *Economics Letters*, 107(3), 350-353.
11. Green, G.P., Richards, T.J. (2018). Discounting environmental goods. *Journal of Agricultural and Resource Economics*, 215-232.
12. GUS (2023). *Główny Urząd Statystyczny*. <https://stat.gov.pl/>
13. International Energy Agency (2022). *Poland 2022. Energy Policy Review*. <https://www.iea.org/reports/poland-2022>
14. Lowe, J. (2008). *Intergenerational wealth transfers and social discounting: Supplementary Green Book guidance*. <https://www.thenbs.com/PublicationIndex /documents/details?Pub=HMT&DocID=303722>
15. Meerding, W.J., Bonsel, G.J., Brouwer, W.B.F., Stuifbergen, M.C., Essink-Bot, M.-L. (2010). Social time preferences for health and money elicited with a choice experiment. *Value in Health: The Journal of the International Society for Pharmacoeconomics and Outcomes Research*, 13(4), 368-374. <https://doi.org/10.1111/j.1524-4733.2009.00681.x>
16. Newell, R.G., Siikamaki, J.V. (2015). *Individual Time Preferences and Energy Efficiency* (Working Paper, No. 20969). National Bureau of Economic Research. <https://doi.org/10.3386/w20969>
17. *Our World in Data* (2024, March 25). Our World in Data. <https://ourworldindata.org>
18. Richards, T.J., Green, G.P. (2015). Environmental Choices and Hyperbolic Discounting: An Experimental Analysis. *Environmental and Resource Economics*, 62(1), 83-103. <https://doi.org/10.1007/s10640-014-9816-6>
19. Stern, P.C. (2000). New Environmental Theories: Toward a Coherent Theory of Environmentally Significant Behavior. *Journal of Social Issues*, 56(3), 407-424. <https://doi.org/10.1111/0022-4537.00175>
20. Stern, P.C., Dietz, T., Abel, T., Guagnano, G.A., Kalof, L. (1999). A Value-Belief-Norm Theory of Support for Social Movements: The Case of Environmentalism. *Human Ecology Review*, 6(2), 81-97.
21. United Nations (2015). Resolution adopted by the General Assembly on 25 September 2015. Transforming our world: The 2030 Agenda for Sustainable Development. In: *Transforming our world: The 2030 Agenda for Sustainable Development*. New York, NY, USA: United Nations.
22. Weitzman, M.L. (1998). Why the Far-Distant Future Should Be Discounted at Its Lowest Possible Rate. *Journal of Environmental Economics and Management*, 36(3), 201-208. <https://doi.org/10.1006/jjeem.1998.1052>
23. Weitzman, M.L. (2001). Gamma Discounting. *American Economic Review*, 91(1), 260-271. <https://doi.org/10.1257/aer.91.1.260>

USE OF SOCIAL MEDIA AND ARTIFICIAL INTELLIGENCE IN CREATING THE IMAGE OF A LEADER IN A LOCAL GOVERNMENT ELECTION CAMPAIGN

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Purpose: presenting the possibilities of using social media and artificial intelligence in creating the image of a leader in the local government election campaign in Poland.

Design/methodology/approach: triangulation of research methods; the election campaign of the candidate for the mayor of Lubin, Lower Silesian Voivodeship in 2024 was analyzed; then a survey of the opinions of Lubin residents was conducted (March–April 2024); the survey was complemented by obtaining the candidate's opinion, and therefore an interview was conducted with him.

Findings: significant information was obtained related to the perception of the elections and candidates as leaders conducting the campaign in social media; in addition, 56.60% of respondents confirmed that information posted on social media has an impact on their voting decisions; 44.34% of respondents trust information about candidates in social media; posts and video materials were indicated as the most engaging content in social media. Regular and frequent publications allow for maintaining the interest and involvement of voters, which is crucial for an effective election campaign. Artificial intelligence can be effectively used during the campaign, among others for the analysis of election data, personalization of the message, automation of responses to comments, creation of newsletters, e-mail marketing, generation of films, images and graphics, and optimization of advertising campaigns.

Research limitations/implications: the study concerns only one election campaign of a specific candidate in local elections in Poland; in order to verify the obtained results, further research could be conducted on the comparison of campaigns of other candidates at the same level of power, other levels of power, or even the comparison of campaigns of candidates from different countries.

Practical implications: conclusions were drawn that were important for election teams and individual candidates, according to which social media are an important tool for attracting voters' attention.

Social implications: indicating modern methods of conducting political campaigns and their impact on local democracy.

Originality/value: previous publications concern mainly presidential campaigns; the value of this article is the analysis at the level of local government elections.

Keywords: image, leader, social media, artificial intelligence, local government elections.

Category of the paper: research paper.

1. Introduction

Image creation is of key importance in economic, social and political activity. This activity concerns organizations (e.g. the image of enterprises), people (i.e. personal branding), brands or events. Creating the image of a leader in local government activity additionally combines issues of leadership and political marketing. Research indicates that in the modern world, social media, including the use of artificial intelligence, play a key (positive and negative) role in creating an image (positive and negative, true and false) (Park et al., 2024). Therefore, work was undertaken to examine the use of social media and artificial intelligence in creating the image of a leader during the local government election campaign in Poland in 2024. The article describes a selected case of the campaign of a candidate for the mayor of Lubin, in the Lower Silesian Voivodeship. The research methods were as follows: a case study covering the candidate's activity in social media, surveys conducted with residents of Lubin and an interview with the candidate. Interesting results were obtained, presenting the discussed topics from the perspective of voters, candidates and the election crowd. An important value of the conducted research is to draw attention to local elections as a field of activity in which artificial intelligence solutions are used. It is therefore indicated that the mechanisms (methods, techniques and tools) of creating a political image used in global and nationwide campaigns are also used at the local level. It is emphasized that the advantages, disadvantages and threats related to the influence of artificial intelligence on the opinion of people (voters) also apply to small communities located in specific regions of the country. This is extremely important, especially since, in addition, 56.60% of respondents confirmed that information posted in social media has an impact on their voting decisions, and 44.34% of respondents trust information about candidates in social media.

2. Creating the image of a political leader in social media – literature review

Local government leadership is a type of political leadership. According to Hartliński, when analyzing the image or characteristics of a leader in politics, it is important to distinguish the concept of political leadership from a political leader. Political leadership concerns the relationship between a political leader and his or her followers and the environment in which they function. On the other hand, the concept of a political leader concerns an individual (a specific person) who leads (Hartliński, 2012). It should be specified that the subject of leadership in this case are large structures or social communities such as: the state, political parties, local community, etc. The main feature of a leader is the ability to inspire the activities

of other people (Bankowicz, 1996). The attributes of a political leader also include: a) the lasting nature of leadership, b) the strategic nature of the decisions he makes, c) having an appropriate political base, d) occupying the highest position in a given political system (Sielski, 2011a). When analyzing the characteristics of a political leader, one should not forget about the universal features attributed to modern leaders, namely: a) interpersonal skills including: communication skill, inspiring and motivating a team, shaping trust, relationships and cooperation with people; b) personal predispositions, which may include: specialist and expert competencies; c) problem-solving skills, taking initiative and personal development are also important here; d) focus on outcomes; e) mastery of change, which includes skills to develop a strategic perspective, connecting the group with the external world, also including its cultural aspect (Balcerzyk, Žukovskis, 2024).

Important from the point of view of creating the image of a political leader is the voluntary nature of the relationship between the political leader and his supporters; the supporters submit to his authority because they consider him to be the only person capable of achieving their common goals (Hartliński, 2012). Additionally, seven factors determining the functioning of party leaders were distinguished:

1. affiliative – becoming a party leader as a result of an agreement within party elites;
2. power – holding positions (party, state or local government);
3. situational – social support;
4. media – media popularity;
5. professional – expert in a given field; union – acquiring trade union leaders;
6. organizational – acquiring leaders of social organizations (Sielski, 2011b).

The fourth attribute is particularly important, according to which the media popularity of a candidate indicates the perception of him as a leader, and not the other way around. The election campaign period is a time of intense competition for the attention and trust of voters. Regardless of whether it concerns a local government, parliamentary or presidential campaign. The main role is played by leaders, who are a kind of political leaders of the groups they represent. Their task is precisely defined, they are to be the "face" of their election committee, and at the same time its driving force. As Grusell and Nord (2023) pointed out, the visual components of political communication are a consequence of the personalization of politics, i.e. focusing attention on candidates and leaders. A characteristic feature of local government leaders in Poland, however, is their declared political independence. Swianiewicz even emphasizes the uniqueness of Polish local governments, which deserve to be called the most partisan in Europe (Swianiewicz, 2024).

Creating an image and message is therefore becoming a complicated undertaking. The ability to effectively reach potential voters through the use of new media and technologies is key in this respect. Building an image on the Internet is an important element of marketing, public relations and, in this case, political strategies. This is particularly important and is gaining in importance in the digital age in which we currently live. Both the Internet and social

media are becoming the main communication channels in the 21st century. According to data presented by DataReportal in cooperation with Meltwater and We Are Social (Digital, 2023), 88.4% of the Polish population are Internet users, and 66.3% of the entire population uses social media; Polish Internet users spend 6 hours and 42 minutes online per day, of which 2 hours and 2 minutes are devoted to social media. The data shows the potential and power of Internet media.

Social media can be an effective tool for marketing communication, provided they are used properly. Individual campaign teams and election committees are increasingly using this tool and are doing so more and more professionally. According to Leszczuk-Fiedziukiwicz (2011), the Internet is the cheapest way to spread information, without time or place limits, in the form given by the content sender. Stoppel (2020), on the other hand, believes that political competition is a specific form of political communication that requires the use of various instruments to achieve the intended goals.

Perloff stated that political communication is primarily the exchange of information between political leaders, the media and citizens. This exchange of information must be attractive and reach a specific recipient. It is therefore not surprising that in the current times, the use of social media in creating the image of a politician or political leader has become an indispensable element of modern communication strategies. Increasingly, election campaigns and candidates themselves reach for new tools and technologies to conduct agitation and present their vision of the world. These tools include, among others:

- Websites – these days, they are a “must have” for every leader. Professionally prepared and designed websites are essential. They provide a lot of important information about the leader, and also serve as a hub for all online activities.
- Blogs/Vlogs – they are an important part that not only serves to self-present a person, but can also build their position as an expert in a given field, as well as attract an interested audience.
- Social media – a powerful tool for promoting your ideas, ideals, self-presentation and contact with voters. Platforms such as Facebook, Twitter, Instagram, Tik-Tok, LinkedIn and YouTube are used to build relationships with recipients. They are also used to communicate key messages and interact with the audience.
- SEO (Search Engine Optimization) – optimization for Internet search engines. A very important tool for websites and blogs to be easily found by users of interest to us.
- Content marketing – creating interesting, diverse and valuable content that attracts and engages a specific audience.
- E-mail marketing (newsletter) – creating personalized information and messages for specific people, sent directly to the recipient's e-mail address.

- Online advertising paid advertising campaigns in search engines (e.g. Google Ads) and on social media platforms (e.g. Facebook Ads) can effectively increase recognition and attract traffic, e.g. to a website.
- Data analysis and media monitoring – a very important thing, although quite often overlooked. Analytical tools and social media monitoring (e.g. Google Analytics, Brand24, SEMrush) allow you to track the effects of online activities. They allow you to understand the behavior of recipients and adjust your marketing strategy in real time.

When it comes to the use of social media in the election campaign, Barack Obama's campaign was a pioneer in 2008. The candidate's modern website included links to 16 sites, including Facebook, Twitter, LinkedIn, and YouTube. In this case, the profile of the then little-known senator from Illinois was exposed on a very large number of sites that reached various social groups. In 2024, it is difficult to find an election committee or candidate who does not use social media to a greater or lesser extent during the election campaign or simply to display their image and contact voters. What is new, however, is the use of artificial intelligence in the election campaign.

According to Deng and Lin (2023), one of the most promising artificial intelligence technologies is ChatGPT, a natural language processing system that can generate human-level conversations. It was developed by OpenAI. It is used, among other things, to understand the context of conversations and generate appropriate responses. Since ChatGPT was launched in 2022, automatic generation of any text has become easy; it also takes much less time than writing a text by a specialist and is much cheaper. The basic version of ChatGPT in version 3.5 is free. However, the extended version ChatGPT 4.0 costs \$20 per month, so such a powerful tool, used in the right hands, can really be very helpful, including in broad marketing activities. It is therefore not surprising that the new technology has entered our lives very strongly and dynamically, including broadly understood politics. Of course, the use of language models such as ChatGPT is not the only novelty. A number of AI-based tools have been created that are key to streamlining various aspects of election campaigns. These solutions include:

- using modern tools to generate content, e.g. posts, photos, videos, graphics or audio generation,
- using various data, including demographics, which allow for adapting the campaign message to specific groups of voters,
- improving communication by integrating chatbots with platforms such as Facebook Messenger, WhatsApp or campaign websites to automate interactions and increase engagement,
- personalizing communication and content, e.g. by adapting the content of advertisements, social media posts and emails to the specific needs and interests of different groups of voters,
- implementing tools for continuous monitoring of campaign effects, thanks to which the strategy can be adjusted in real time, increasing its effectiveness.

There are many advantages to using social media by politicians, including:

- no need for specialist knowledge to use them,
- relatively low financial outlays for running them,
- short time needed to publish content compared to traditional media,
- easy and quick way to edit content,
- the ability to establish direct relationships with users,
- building long-term relationships.

However, it is important to be aware that artificial intelligence also involves significant threats. The most important potential risks associated with the use of artificial intelligence in the electoral context include:

- Deepfake and audiovisual manipulation – increasingly used technology, which involves creating realistic and difficult to distinguish fake video or audio materials. These manipulations most often depict public figures saying or doing things they never said or did.
- Data manipulation – unauthorized use of personal data for political purposes, such as targeting voters to manipulate their preferences and voting behavior.
- Impact on access to information – inequalities in access to information can affect the level of public awareness and equal opportunities to participate in the democratic process, algorithms summarizing specific content for voters, difficulty in determining the credibility of information and its source.

The above-mentioned features still arouse fear and distrust among conscious media users (Balcerzyk, Czainska, 2024).

Artificial intelligence in election campaigns is a relatively new phenomenon. At the moment, there are no clear legal regulations that could supervise and shape its use in a responsible and safe manner. Although the first positive premises are emerging in this regard.

3. Methodology

Before starting the research, the following research question was formulated: *how do modern information and communication technologies affect electoral decisions and the creation of political image?* The main research objective of the work was to assess how social media and artificial intelligence affect the effectiveness of election campaigns in the local context and how these technologies can be used to improve political communication and citizen engagement. Two specific objectives were also adopted:

- analysis of the use of social media and artificial intelligence by candidates during elections,
- study of the impact of social media on the voting behavior of residents.

In addition, two research theses were also formulated:

T1: Social media as a tool for shaping opinions: *social media have a significant impact on the outcome of election campaigns in local government elections, by shaping the perception of candidates and their programs by residents.*

T2: The role of artificial intelligence in election campaign strategies: *Artificial intelligence is actively used by candidates in local government campaigns to personalize communication and analyze election data, which contributes to increasing the effectiveness of their election activities.*

The study used a translation of techniques, namely the following were carried out: case study, survey and interview. The presented case study analyses Piotr Borys's activity in social media during the election campaign for the mayor of Lubin, from the moment of announcing his candidacy on 19 December 2023 to 8 April 2024, when the results were announced by the National Electoral Commission; the analysis includes the number, type and frequency of published posts, as well as an assessment of the effectiveness of the forms of content used; the main goal is to understand how and with what effect social media is used to create a political image and engage voters by the candidate for the mayor of the city of Lubin. Second step of research project was the survey among Lubin residents. 106 residents of the city took part in the survey during the election campaign; the survey was conducted at the turn of March and April 2024, using the PAPI (Paper and Pen Personal Interview) technique, i.e. information from respondents was obtained in the form of a direct interview conducted by an interviewer using a paper form; the subject of the survey was the behavior of voters on social media, their interactions with content published by the candidate and the impact of these interactions on the perception of the candidate and his program by respondents. The last part of the study was an interview with the candidate and his campaign staff. The interview with the candidate and members of his campaign team took place at the candidate's campaign headquarters, which provided an excellent opportunity to gain a first-hand understanding of the strategies and tools used by the team during the campaign; the purpose of the interview was to gain detailed information about the use of AI in the election campaign, understand the benefits and challenges associated with its use, and determine the campaign's future plans for AI technology; six key open-ended questions were asked; the interview lasted approximately 45 minutes, allowing for a comprehensive discussion of the topic and obtaining valuable information for analysis.

4. Results

4.1. Analysis of the selected candidate's campaign on social media

The candidate focused his promotional activities mainly on the Facebook platform. The candidate's communication strategy included using two different profiles - a private one, which had 4.9 thousand friends and an official one - with 12 thousand followers. Piotr Borys also ran a campaign on Instagram, Tik-Tok, YouTube and Twitter.

During the campaign, which was officially conducted by the candidate from the announcement of his participation in the elections, which took place on December 18th 2024, over 175 posts were posted on Piotr Borys' private FB profile, which translates to an average of about 1.56 posts per day. The politician's official profile published 97 posts regarding the local elections, with the intensity of publications increasing only from the second half of February 2024. It is worth noting that only those posts that were directly related to the election campaign and posted directly by the candidate were analyzed, omitting posts tagging the candidate made by other users or strictly related to Piotr Borys' work. The campaign lasted 112 days, during which time the candidate published 175 posts on his private fanpage on Facebook. On the public fanpage, his electoral activity lasted from February 15, 2024 to April 8, 2024. During this time, 97 posts were published, which is an average of 1.83 posts per day. On the private fanpage, the structure of published posts was as follows:

- Video posts: 61 posts (34.9% of all posts).
- Reels: 13 posts (21.3% of all video posts and 7.4% of all posts).
- Podcast – 4 posts (2.3% of all posts).
- Live coverage – 7 posts (4.0% of all posts).
- Other posts: 90 posts (51.4% of all posts).
- Video posts: 47 posts (48.5% of all posts).
- Reels: 11 posts (23.4% of all video posts and 11.3% of all posts).
- Podcasts: 3 posts (3.1% of all posts).
- Live coverage: 5 posts (5.2% of all posts).
- Other posts: 42 posts (43.3% of all posts).

The number of video posts added on both FB accounts indicates that both the candidate and his campaign team have focused strongly on this type of content, which is undoubtedly one of the key elements of modern election campaigns. They enable direct communication with voters and engaging them with dynamic and visually appealing content. Video materials enjoyed great interest and were most frequently published and promoted on the candidate's fan page. The most attention was drawn to materials in which the candidate was supported by well-known figures from public life (e.g. the support of the mayor of Warsaw, Rafał Trzaskowski, generated 48,000 views, 140 reactions and 18 comments). The candidate also used paid advertisements

on Facebook and Instagram (Facebook Ads). It should be noted that paid advertisements in the case of elections can only be placed by verified candidate accounts and paid for by individual campaign teams. Each advertisement must be marked in social media as financed by a given election committee. Therefore, only the candidate's public profile was analyzed in this work. From 18.12.2023 to 08.04.2024, 24 paid social media campaigns were created.

The candidate's paid campaigns on Facebook and Instagram reached an estimated audience of around 1,134,800 people (based on the sum of the average values of the estimated audience). The total number of views was around 800,000. The total cost of the advertising campaigns ranged from PLN 8500 to PLN 10,400. The above data indicates a significant level of visibility of the campaign in social media. These campaigns were a key element of the marketing strategy, aimed at increasing voter recognition and engagement. Piotr Borys' advertising campaigns on Facebook and Instagram were well-organized and effective, achieving wide audience reach and high engagement at moderate costs. Additionally, during the campaign, 52 posts appeared on the candidate's Instagram. These were the same posts that the candidate posted on his Facebook fanpage. On Twitter (X), on the other hand, only two posts related to Piotr Borys' run for mayor of Lubin appeared throughout the campaign. The YouTube channel was not used in the election campaign even once. A similar situation occurred on TikTok.

4.2. Survey research

The distribution of respondents by gender was as follows: 55 women and 51 men. In the study group, 18.87% of respondents were people aged 18-29, 19.81% were people aged 30-39, the largest age group was made up of people aged 40-49 (21.70%), the same number of people (19.81% each) were in the age group of 50-59 and 60+. In terms of education, among the survey participants, 21.70% had primary education, 38.68% secondary education, 33.02% higher education, and 6.60% declared other forms of education.

The majority of respondents (65.09%) took part in the recent local elections in Lubin, while 34.91% responded that they did not take part. The next question, in which more than one answer could be selected, concerned the social media platform that respondents use most often. The most popular was Facebook, which was indicated by 74 respondents. Instagram came second, (53 people). Tik-Tok (42 people), Twitter (31 people) and LinkedIn (28 people) came next.

The next question concerned the amount of time spent by respondents on browsing social media. Most respondents (38.68%) spend 1-2 hours per day browsing social media, 29.25% spend less than an hour, 18.87% 3-4 hours, and 13.21% more than 4 hours. Let us recall that in a report prepared by DataReportal in cooperation with Meltwater and We Are Social, it was found that Polish internet users spend 6 hours and 42 minutes online (Digital, 2023). More than half of respondents among Lubin residents (55.55%) spend from 1 to 4 hours browsing social media every day.

The next question concerned the information posted on social media and its influence on voting decisions. The results show that the majority of respondents (56.60%) believe that information found on social media has some influence on their voting decisions, although only 31.13% state that this influence is significant. On the other hand, 43.40% of respondents believe that social media has no influence on their voting decisions (fig. 1).

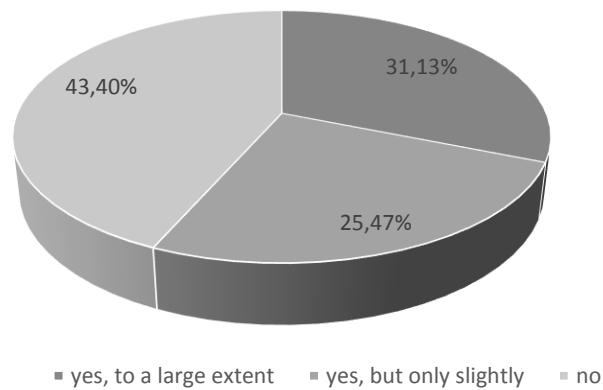


Figure 1. The influence of social media on voting decisions.

Source: own study based on conducted research.

It can be stated that the respondents perceive the role of social media in making electoral decisions in different ways. However, it is worth emphasizing that for more than half of the respondents, social media play a fairly significant role during the election campaign and have an impact on their decisions.

The results of the next question regarding whether respondents trust information about individual candidates posted on social media are also interesting. In this case, as many as 44.34% of respondents trust information about candidates in social media, 36.79% do not trust it, and 18.87% do not have an opinion on the subject (fig. 2). These results can be interpreted as meaning that almost half of respondents trust content published on social media that is directly related to candidates in the elections.

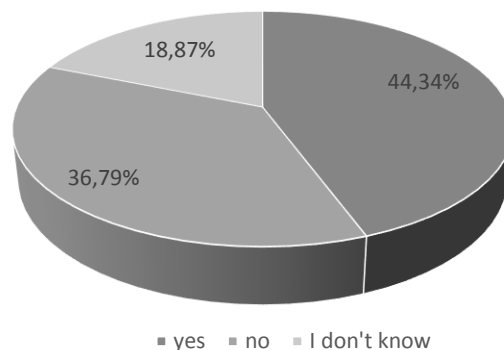


Figure 2. Trust in information about candidates on social media.

Source: own study based on conducted research.

The next question was whether social media have a positive impact on the electoral process. The largest number of respondents, i.e. (46.23%), answered this question in the affirmative. On the other hand, 40.57% believe that social media have a negative impact on the electoral process. 13.21% have no opinion on this issue. It is worth adding that people in the age group of 50+ (73%) have a negative opinion on this subject.

The answers to the question about changing one's mind about a candidate based on information from social media are also interesting. The majority of respondents (68.87%) indicated that this type of information did not influence the change of mind about a given candidate. Only 33 respondents admitted that this information influenced the change of their perception of the candidate. The obtained results may suggest that despite the fact that social media, as a place of distributing information about candidates, are a popular channel for this purpose, their influence on changing the opinion about candidates is quite limited (fig. 3).

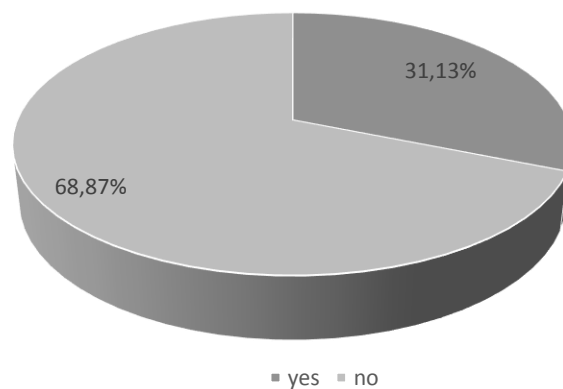


Figure 3. The influence of social media on changing minds about candidates.

Source: own study based on conducted research.

The survey also asked respondents about the frequency with which they interact with political content on social media. This included “liking”, commenting or sharing posts. The results show that users’ activity in this type of interaction varies greatly. The largest number of respondents, 34.91%, rarely engage in such activities, which may indicate occasional interest or limited willingness to publicly express opinions on political topics. 29.25% of respondents never interact with political content on social media. This may suggest a lack of interest or a conscious decision to avoid politics on social media. On the other hand, 19.81% of participants often interact, showing regular interest in the topic. The fewest people answered that they very often interact with political content (16.04% of respondents). This answer may indicate the strong involvement of this group in current political discussions.

The next question determined how often respondents engage in following candidates' political profiles on social media. The largest number of respondents, 34.91%, responded that they rarely follow political profiles. This may indicate limited interest in politics or selective engagement only when the subject seems important to them. "Never" was indicated by 32.08%, or 34 respondents. This answer may be a clear signal that this group avoids politics on social

media for various reasons. 24.53% of people responded that they follow political profiles on social media, but only during the election campaign. This answer confirms seasonal interest in politics. On the other hand, the fewest, only 9 people, responded that they regularly follow candidates' political profiles. This is the group that is most involved in political events. However, this question clearly shows that most respondents engage in following political profiles sporadically or not at all.

Respondents were also asked whether they had ever noticed false information about candidates or elections on social media platforms (fig. 4). One third of respondents answered this question affirmatively, which may indicate, on the one hand, a fairly high awareness of the presence of disinformation and fake news in the area of social media. On the other hand, this may have a negative impact on the perception of social media as a place of credible information. 28.30% of respondents stated that they had never noticed false information about candidates or elections. On the other hand, the largest number of respondents, 38.68%, are not sure whether they have encountered information in social media that was or could be false. From the answers provided, it can be concluded that the problem of false information in social media is significant and affects a large number of users. Almost one third of respondents are aware of manipulation and disinformation, and almost 40% of people are not sure about the authenticity of the information they have come across.

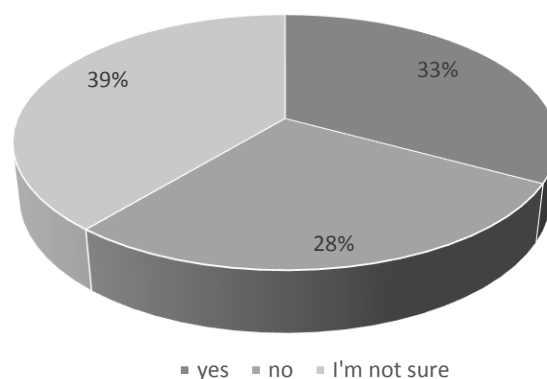


Figure 4. Awareness of fake news on social media.

Source: own study based on conducted research.

The survey also asked whether respondents believed that social media should be more closely monitored during election campaigns. 48.11% of participants did not have a firm opinion on the subject. This may indicate that the indecision in this case may result from a lack of full understanding of the consequences of monitoring social media, especially during election campaigns, and what consequences it may entail. On the other hand, 29.25% of respondents did not support tightening monitoring. In this case, respondents may believe that stricter regulations could violate freedom of speech or limit the freedom to express opinions. The fewest, 22.64% of respondents, were in favor of increased supervision. And here we may be dealing with people who may be concerned about the potential impact of disinformation and

manipulation on elections. Therefore, they tend to support more stringent regulations in social media.

The next question concerned the type of electoral content in social media that most attracts the attention of respondents (fig. 5). The largest number of people (31.13%) indicated posts as the most engaging type of content. Text or graphic posts can effectively attract attention thanks to their direct message and ease of interaction. 25.47% of respondents prefer video content. It is worth emphasizing that this format, especially in the digital era, is very attractive due to its dynamics and the ability to convey complex information in an accessible way. In third place were photos published in social media, this option was indicated by 19.81% of respondents. The visual presentation of information can be a strong magnet for the electorate. 15.09% of respondents pay attention to paid advertisements. Although they are often perceived negatively, they can effectively reach a large group of recipients with a precisely tailored message. In last place were banners, which were indicated by 8.49% of respondents. Currently, it is a less popular form of content, but it still finds its supporters who primarily value its visual appeal and conciseness of the message.

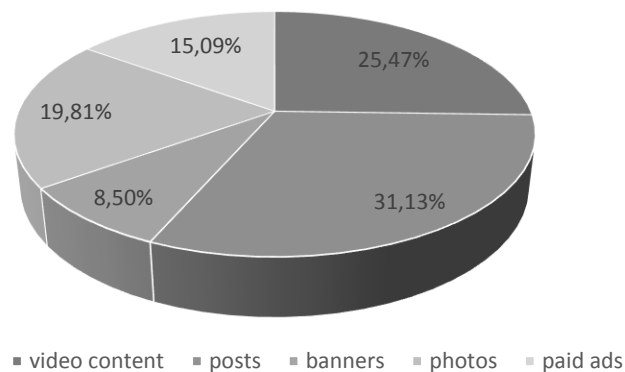


Figure 5. Social Media Electoral Content Preferences.

Source: own study based on conducted research.

In the next question, respondents were asked whether they believed that candidates presented themselves authentically on social media. As many as 38.68% of respondents answered negatively, claiming that candidates presenting themselves on social media are not authentic. On this basis, it can be concluded that candidates often create their images in a way that serves to gain popularity or votes, and does not reflect their true attitudes and beliefs. In turn, 33.02% of respondents believe that candidates present themselves authentically. This group perceives candidates' communication as credible and believes that information posted on social media is reliable and true. The answer "hard to say" was "difficult to say" by 28.30% of participants. In this case, the indicated group may have difficulty in clearly determining whether presentations and content posted on social media are authentic. Indecision may result from a lack of sufficient information or difficulties in assessing the authenticity of information posted by candidates on social media.

In the last question, respondents were asked where they get information about the current election campaign from. The largest number of respondents, 62.26% of respondents, indicated “Traditional media” and “Social media” as their main sources of information. This indicates that both traditional and modern content channels have a strong position in transmitting political news. This also indicates the complexity of the media landscape in which we live. The next place was taken by “Printed media (leaflets, posters, billboards)”, indicated by 21.70% of respondents. This means that despite digitalization, traditional methods of communication still have their place, especially in local election campaigns (fig. 6).

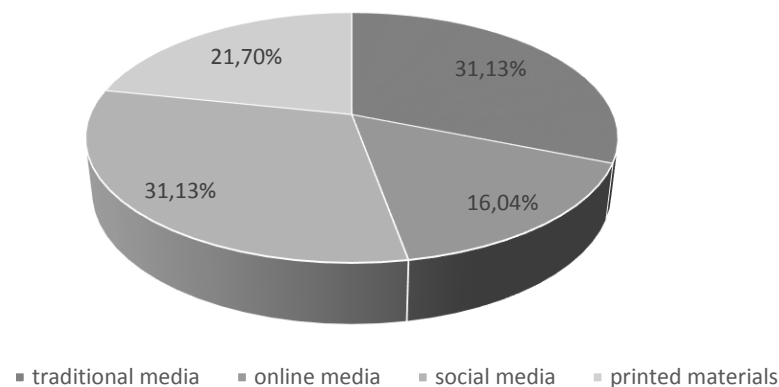


Figure 6. Sources of information about the election campaign among respondents.

Source: own study based on conducted research.

4.3. Interview with the candidate and the election team

The first question was whether artificial intelligence was used in Piotr Borys's election campaign. The answer was yes. The campaign team used AI technology in various aspects of the election campaign.

The next question was of a clarifying nature and concerned the areas in which artificial intelligence was used in the campaign. Piotr Borys's staff used AI in the following areas:

- video editing, which sped up the video content production process,
- Descript was used to transcribe text from video and add subtitles to reels,
- AI-generated voiceover database from ElevenLabs was used to create narration in various types of campaign spots and materials that were broadcast on the candidate's social media,
- ChatGPT was occasionally used to generate posts for social media; this tool was also used to correct the content of individual posts, including appropriate hashtags and emoticons.

The next question concerned what AI-based tools the candidate's campaign team used. The Descript program was most often used during the campaign, which was primarily used to transcribe text from video materials. Then, subtitles were automatically generated for short video forms, such as Facebook reels. Automatic subtitle generation increased the accessibility

and comprehensibility of the content for a wider audience. The possibilities offered by the ElevenLabs program were also used several times. This is a database of AI-generated narrators. All you need to do is enter the desired text and select the appropriate narrator, and within a few minutes you have a ready audio file. Thanks to this technology, it was possible to create professional narrations for election films, which increased the quality and attractiveness of the video materials. As the candidate's campaign team emphasized, this program first of all saved a lot of time and money. During the campaign, ChatGPT from OpenAI was also used to generate posts for social media. In this case, AI helped create engaging content, which contributed to increased interaction and engagement of the recipients.

The candidate and his campaign team were asked whether and what benefits they had noticed from using artificial intelligence in the election campaign. In response to this question, the most important thing was increased efficiency and speed. AI significantly sped up the processes of video editing, transcription and adding subtitles, which allowed for faster publishing of content. The greater professionalism of the published content was also emphasized, here as an example the generation of voice-overs by ElevenLabs, which ensured high quality of narration in video materials. The last issue that the candidate's campaign team paid particular attention to was the automation of creating posts, which allowed for better adaptation of messages to recipients, which translated into their greater engagement.

The final question asked whether the candidate and his campaign team intend to continue or expand the use of AI in future election campaigns. The answer was yes. Piotr Borys' campaign team expressed interest in continuing and expanding the use of AI in future election campaigns. There are plans to continue experimenting with AI tools to further increase the efficiency and effectiveness of their marketing activities.

5. Discussion

The conducted research yielded results confirming the conclusions formulated by other authors, according to which contemporary election campaigns effectively use social media and artificial intelligence in creating candidates' image and influencing voters' opinions. This also confirms the thesis that *AI is actively used by candidates in local government campaigns to personalize communication and analyze election data, which contributes to increasing the effectiveness of their election activities* (T2). It has not been unequivocally confirmed that the use of new technologies by election staff raises voters' concerns; the results obtained, for example, in terms of the level of trust in published content indicate a significant polarization of society. Therefore, the first thesis (T1) cannot be confirmed either, because social media obviously have an impact on the perception of the candidate, but it cannot be stated that this is a "significant" impact and influencing the electoral decision.

The main research objective was to assess how social media and artificial intelligence affect the effectiveness of election campaigns in the local context and how these technologies can be used to improve political communication and citizen engagement. By understanding these mechanisms, the work aims to contribute to the theory and practice of modern political campaigning methods and their impact on local democracy.

The study is not without limitations, it concerns only one election campaign of a specific candidate in local elections in Poland; in order to verify the obtained results, further research could be conducted on the comparison of campaigns of other candidates at the same level of power, other levels of power, or even the comparison of campaigns of candidates from different countries.

6. Summary

The survey conducted yields interesting conclusions. Over 55% of people using the internet spend 1 to 4 hours a day on social media. This shows that most respondents spend a significant part of the day browsing content on social media. In addition, 56.60% of respondents confirmed that certain information posted on social media influences their voting decisions. Additionally, 44.34% of respondents trust information about candidates on social media. Respondents indicated posts and video materials as the most engaging content on social media. This is a clear signal to campaign teams and individual candidates that social media is a powerful tool for attracting voters' attention. Adopting an appropriate strategy for running an online campaign, or more precisely, in social media, can bring candidates tangible benefits.

It is worth emphasizing that the candidate used two separate fan pages (on Facebook) for election agitation: public and private, which could have caused some confusion among voters, because of different content, which could have led to disorientation and made it difficult to clearly perceive the election message. Such a strategy could, on the one hand, increase the reach of messages, but on the other hand, blur the coherence of the message, which is key to building a clear image of the candidate. A serious mistake was also to conduct the campaign at different times on both profiles. The campaign on the private profile began after the announcement of running in the elections on December 19, 2023, while the campaign on the public profile did not start until mid-February. Analyzing the content posted on social media, Piotr Borys's campaign team focused on publishing video materials and typical posts reporting on events from the election campaign, based on text and photo coverage. The main conclusion is that there was too little diverse content on social media. Only four podcasts and a few live broadcasts were definitely not enough. There was no possibility of asking questions to the candidate during live sessions on Facebook and more live reports from various types of events organized during the campaign. Another big mistake was posting several posts with similar content in a single

day, in short intervals, e.g. three video materials in a row. This led to a decrease in the reach of published posts. There was also a lack of interaction in comments with voters, including responding to posted comments.

On the candidate's Facebook profile, the so-called election-related materials enjoyed great interest from the audience. Posts about the candidate's life, for example a post in which the candidate played sports (running), generated a very large number of likes, shares and comments. Unfortunately, this type of content was posted very rarely. It is worth considering publishing posts about the candidate's life more often, thanks to which potential voters could get to know him better. They could see what he likes to do in his free time, whether he likes cooking, eating out, whether he prefers going to the cinema or the theatre, etc. There was also a lack of showing the campaign from behind the scenes. Posts and videos from backstage, such as the candidate's verbal blunders, moments before meetings with voters, or preparations for important speeches, could add authenticity and increase the audience's engagement. Such content helps build a bond with voters by showing the human side of the candidate and the hardships and challenges associated with running a campaign.

Despite the fact that Facebook enjoyed the greatest interest during the election, the candidate did not use the full potential of social media. Platforms such as TikTok, YouTube or Twitter (X), which could also attract a significant number of voters, were almost completely omitted. Each of these platforms offers unique opportunities to reach different audiences and amplify the election message. Apart from Facebook, content was published only on Instagram. Unfortunately, these were not unique materials, but the same ones that had previously appeared on Facebook. In total, the candidate posted 53 posts during the 112 days of the campaign, which is an average of 0.47 posts per day. This is definitely not enough to maintain constant engagement and interest of voters.

TikTok, with its short and dynamic videos, could help reach younger voters who often prefer quick and visually engaging content. YouTube, as the world's second largest search engine, offers the possibility of publishing longer videos that can provide an in-depth presentation of the candidate's campaign platform and achievements. Twitter (X), with its dynamic and direct form of communication, could be used for ongoing interaction with voters and quick response to campaign events. Integrated and thoughtful use of these platforms could significantly increase campaign reach and voter engagement, which is key to building a strong and coherent image of the candidate.

To maintain consistent voter engagement, it is recommended to increase the frequency of posting to at least 1-2 posts per day across all of the candidate's social media platforms during the election campaign. Regular and frequent posting will help to keep voters engaged and engaged, which is crucial for a successful election campaign. It is also important to create unique content across different social media platforms. Posting original content on each platform can attract a diverse audience and significantly increase the reach of your campaign. Expanding your presence on other social media platforms such as TikTok, YouTube,

and Twitter (X) is the next step. These platforms offer unique features that can be used to reach a wider group of voters and increase the visibility of your campaign. It is also recommended to increase interaction with voters by actively responding to comments, hosting live Q&A sessions, and engaging in discussions across platforms. Such interactions can significantly strengthen the bond with voters and build trust. Another important step is to increase the diversity of the content you post.

Another important issue is the use of paid advertising in social media. Piotr Borys and his team, as shown in this work, used this promotional tool, which provided the published content with measurable benefits, in the form of greater reach, more views and increased interaction with recipients. It is recommended to continue using paid advertising, e.g. Facebook Ads, which, above all, will allow for increased reach and visibility, the possibility of precise targeting and analysis and optimization possibilities practically in real time.

Finally, it is recommended to regularly analyze the results of publications on various platforms and adjust the strategy in order to maximize the engagement and effectiveness of the campaign. Continuous monitoring and optimization of activities will allow for better adaptation of the campaign to the needs and expectations of voters, which in turn will translate into better election results.

It is worth emphasizing that Piotr Borys's campaign team used various AI-based tools during the election campaign. However, they focused primarily on helping to create video materials for social media, and were occasionally used to generate post content. However, AI could be better used during the campaign, including for analyzing election data, personalizing messages, automating responses to comments, creating newsletters, e-mail marketing, generating videos, images, and graphics, and optimizing advertising campaigns. The candidate should consider integrating modern AI tools into his campaign to increase the effectiveness of his activities and better respond to the needs of voters. It is recommended to continue and expand the use of AI in future campaigns, especially in areas that have not been intensively used so far.

Candidates must constantly analyze their environment and follow new trends in online marketing. Creating an image in social media requires constant adaptation to changing user preferences. In addition, the election team should focus more and more attention on the use of artificial intelligence in the election campaign. Thanks to automation, AI can save time and money and significantly facilitate and accelerate contact with potential voters, which is crucial for an effective and modern election campaign.

References

1. Balcerzyk, D., Czainska, K. (2024). Trust in Artificial Intelligence and the 5.0 leadership. In: I.M.M. El Emary, A. Brzozowska, P. Maśloch (Eds.), *Digital Synergy: Innovative Approaches of Management in ICT Era* (pp. 94-100). Boca Raton: CRC Press Taylor & Francis Group.
2. Balcerzyk, D., Žukovskis, J. (2024). Determinants of managerial competencies in the Leadership ecosystem 5.0. *Silesian University of Technology Scientific Papers. Organization & Management Series. no. 191*, pp 27-40, doi: 10.29119/1641-3466.2024.191.2.
3. Bankowicz, M. (1996). *Słownik polityki*. Warszawa: Wiedza Powszechna.
4. Deng, J., Lin, Y. (2023). The Benefits and Challenges of ChatGPT: An Overview. *Frontiers in Computing and Intelligent Systems*. Retrieved from: <https://www.semanticscholar.org/paper/The-Benefits-and-Challenges-of-ChatGPT%3A-An-Overview-Deng-Lin/57be0eee785bbfd669c1f51e9a3681105b7f82be>
5. Digital (2023). *Digital 2023 – najnowszy raport dotyczący Internetu w Polsce*. Retrieved from: <https://www.znajdzreklame.pl/blog/kampanie-internetowe/digital-2023-najnowszy-raport-dotyczacy-internetu-w-polsce/>
6. Grusell, M., Nord, L. (2023). Not so intimate Instagram: Images of Swedish political party leaders in the 2018 national election campaign. *Journal of Political Marketing*, 22(2), pp. 92-107, <https://doi.org/10.1080/15377857.2020.1841709>.
7. Hartliński, M. (2012). *Przywództwo polityczne*. Olsztyn: Instytut Nauk Politycznych Uniwersytetu Warmińsko-Mazurskiego w Olsztynie.
8. Leszczuk-Fiedziukiewicz, A. (2011). Internet jako narzędzie kreowania wizerunku polityka. *Nowe Media*, no. 2, pp. 31-54. <https://doi.org/10.12775/NM.2011.002>.
9. Park, P.S., Goldstein, S., O’Gara, A., Chen, M., Hendrycks, D. (2024). AI deception: A survey of examples, risks, and potential solutions. *Patterns*, 5(5), pp. 1-16. doi: 10.1016/j.patter.2024.100988.
10. Perlof, R.M. (1998). *Political Communication. Politics Press and Public in America*. New Jarsey/ London: Routladge.
11. Sielski, J. (2011b). Liderzy partyjni we współczesnych polskich partiach politycznych. In: K. Kowalczyk (Ed.), *Partie i system partyjny III RP*. Toruń: Wydawnictwo Adam Marszałek.
12. Sielski, J. (2011) Teoretyczne ujęcie przywództwa politycznego. Studium przypadku – Polska. In: W. Konarski, A. Durska, S. Bachrynowski (Eds.), *Kryzys przywództwa we współczesnej polityce* (pp. 147-160). Warszawa: SWPS „Academica”.

13. Stoppel, A. (2020). *Nowe Media w Polityce na przykładzie kampanii prezydenckich w Polsce w latach 1995-2015*. Poznań: FNCE.
14. Swianiewicz, P. (2024). *Radnych gminnych portret własny (na tle europejskim)*. Łódź: Narodowy Instytut Samorządu Terytorialnego. Retrieved from: https://archiwum.nist.gov.pl/files/texts/4787_17254554962053.pdf

SUSTAINABLE PRACTICES IN ENTERPRISES IN THE CONTEXT OF ICT DEVICES USAGE

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Purpose: Study on the level of implementation of sustainable practices in Polish enterprises in the field of ICT equipment management in NUTS-2 regions in Poland.

Design/methodology/approach: The study employs methods of multivariate statistical analysis to comprehensively assess and compare the extent of sustainable ICT practices in different regions. Data from the Polish Central Statistical Office for 2022 were analysed, focusing on five key indicators: reduction of printed paper, energy efficiency measures for ICT, environmentally conscious ICT procurement, proper disposal of electronic waste, and practices of reusing or returning ICT equipment.

Findings: The results reveal significant regional disparities. The Warszawski Stołeczny region leads in implementing sustainable ICT practices, underpinned by advanced infrastructure and a high degree of environmental awareness among enterprises. In contrast, regions like Lubuskie and Mazowiecki Regionalny exhibit lower levels of pro-environmental ICT activities, reflecting weaker economic conditions and infrastructure. The research supports the hypothesis of a positive correlation between regional economic development and the implementation of sustainable ICT practices.

Research limitations/implications: The study's limitations include reliance on data from a single year, restricting the ability to identify trends over time. Future research could extend to longitudinal analyses and explore additional variables, such as the influence of regional policies or cultural factors on environmental practices.

Practical implications: The findings can guide policymakers and regional authorities in designing targeted interventions to promote sustainable ICT management, especially in less developed regions. Businesses may use these insights to align their practices with regional benchmarks, enhancing both environmental performance and regulatory compliance.

Social implications: The research informs policy measures and corporate social responsibility initiatives, ultimately contributing to improved environmental outcomes and public awareness.

Originality/value: This study provides a novel regional analysis of sustainable ICT practices in Poland, offering a valuable framework for comparing and improving environmental management across diverse economic landscapes. It is relevant to policymakers, environmental researchers, and business leaders.

Keywords: sustainable ICT practices, regional analysis, multivariate analysis, environmental management, corporate social responsibility.

Category of the paper: Research paper.

1. Introduction

In the face of growing challenges related to environmental protection and sustainable development, enterprises must adapt their practices concerning the use of information and communication technologies (ICT) in a responsible and eco-friendly manner. In an era of dynamic technological advancement, the use of ICT devices has become indispensable; however, their production, operation, and disposal can generate significant environmental burdens. In this context, there is a need to identify and evaluate sustainable ICT management practices in enterprises.

This article aims to examine the level of implementation of sustainable practices in Polish enterprises regarding ICT management across NUTS-2 regions in Poland. These regions encompass the administrative division of Poland, including the specificity of the Mazowieckie Voivodeship, which is split into the Warsaw capital region and the Mazowiecki regional area.

The research hypotheses are as follows:

1. There are significant differences in the implementation of sustainable ICT practices between regions in Poland, which may result from varying economic development levels and environmental awareness.
2. The Warsaw capital region is characterized by a higher level of implementation of eco-friendly actions in ICT management compared to other regions.
3. A higher level of economic development in a region (measured by the development index) is correlated with more frequent adoption of sustainable ICT practices.

The study used publicly available data from 2022, obtained from the Polish Central Statistical Office, concerning the impact of ICT devices on the environment within the Polish economy. The data analyzed pertain to the percentage of enterprises that consider selected environmental aspects within designated administrative areas of Poland.

1. Overview of sustainable business practices

Recent research on ICT equipment and environmental protection highlights both positive and negative effects. While ICT can improve environmental sustainability through digitalization and energy efficiency (Charfeddine, Umlai, 2023), it also contributes to CO₂ emissions and energy consumption (Siddiqui et al., 2014; Bull, 2015). In turn, Szalkowski et al. (2024) in a review of the scientific literature identified eight main classes of solutions regarding the impact of ICT on the environment, aligning them with the UN Sustainable Development Goals. Bieser and Hilty (2018) also assessed the indirect negative environmental effects of ICT in their research. To mitigate the negative effects of ICT, researchers propose,

for m.in, environmentally friendly devices and green computing approaches (Siddiqui et al., 2014). A review of the literature on the pro-ecological activities of enterprises in the use of office equipment confirms the possibility of reducing energy consumption in office environments. Studies have shown that optimizing the location and allocation of printing devices can lead to significant reductions in electricity consumption and carbon emissions (Kaszyński et al., 2021). Deploying energy-efficient ICT equipment and promoting good practices such as proper device management and energy-saving settings can further reduce energy consumption in commercial buildings (Kamilaris et al., 2014; Wysocki, 2016). In addition, the scientific literature confirms that the use of ambient technologies to increase awareness and encourage employees to compete effectively reduces the energy consumption associated with lighting in public areas of office buildings (Coutaz et al., 2018). Other research indicates that promoting eco-friendly printing behaviour can significantly reduce paper consumption and associated costs in offices. A study conducted in Dutch primary schools found that reinforcing pro-ecological values led to a 45-51% reduction in printing (Suleri, 2018). Other studies on green printing behavior also support these findings (Suleri, Cavagnaro, 2016). Companies that adopt proactive environmental strategies can gain a competitive advantage by reducing costs, improving product quality, and better relationships with stakeholders (Seroka-Stolka, 2012). These results indicate that the promotion of sustainable values and the use of technology can effectively reduce printing and its environmental impact in various areas.

Another problem in the field of office equipment is its disposal. Recent research highlights the importance of efficient collection systems for waste electronic equipment (Anuradha, 2024; Lu et al., 2017; Friege et al., 2015). This is also becoming an area that requires procedural changes in office management in enterprises.

2. Methodology

The study used publicly available data collected from the website of the Central Statistical Office (GUS) on pro-ecological practices in enterprises in the area of the use of ICT equipment in 2022 Polish. In particular, comparative analyses were used, which allow for a comprehensive grasp of the complex phenomenon of implementing pro-ecological practices and the assessment of regional differences in this area. These methods are particularly useful for the purpose of the article for several reasons. Firstly, they allow the assessment of a complex phenomenon – the variables used in the study relate to different aspects of the sustainable management of ICT devices, which creates a complex picture of the pro-environmental activities undertaken by companies. Multivariate methods allow these variables to be combined into one coherent index that synthetically describes the level of implementation of sustainable practices. The variables analysed include: the share of companies reducing paper printing, the share of companies

reducing the energy consumption of ICT equipment, the share of companies taking environmental protection into account when choosing ICT equipment, the share of companies returning waste equipment to appropriate collection points, and the percentage of companies selling, charitable or returning unused equipment to the lessor. Secondly, these methods make it possible to identify differences between regions (voivodeships). By using measures of distance from the development pattern and the development index, it is possible to determine how different regions differ in terms of the advancement of pro-ecological activities. Comparative analysis takes into account the multifaceted nature of the phenomenon, which allows for accurate identification of regions ahead and lagging behind the pattern. Thirdly, in the context of this study, these methods make it possible to rank and classify regions according to the level of implementation of sustainable practices. This makes it possible to identify those regions that require specific support in the field of sustainable management practices of ICT equipment in enterprises.

In the methods of multivariate statistical analysis, and especially in the methods of linear ordering, it is important to distinguish variables according to their nature. We distinguish stimulants, i.e. variables whose higher values are desirable in the context of the phenomenon under study, destimulants, i.e. variables where higher values are unfavorable, and nominates for which deviations from the optimal level are undesirable (Zawada, 2009). Linear ordering methods are widely used, in particular when assessing the diversity of objects due to the level of economic development achieved. The study assumed that the level of influence of all variables (X1-X5) on the analyzed phenomenon is the same. The similarity of objects (the closer the values of the variables describing a given complex phenomenon, the more similar the objects are to each other) was measured by the distance between objects, which assigns one value to two objects. Thus, the Euclidean distances of individual objects in relation to the model object were determined (Mesjasz-Lech, 2018):

$$d_{i0} = \sqrt{\sum_{j=1}^m (z_{ij} - z_{0j})^2} \quad (i=1, \dots, n) \quad (1)$$

whereas,

$$z_{0j} = \begin{cases} \max_i z_{ij} & \text{for stimulants} \\ \min_i z_{ij} & \text{for destimulants} \end{cases} \quad (2)$$

The measure of development was estimated using the formula:

$$m_i = 1 - \frac{d_{i0}}{d_0} \quad (i=1, \dots, n), \quad (3)$$

For such a measure of development with values in the range [0,1], it is assumed that the higher its value, the higher the level of the phenomenon under study.

The methodological approach adopted allows for an in-depth analysis of the phenomenon, as well as offers tools to identify and assess potential regional differences. The results of the analysis will provide comprehensive knowledge on the spatial diversity of the implementation of pro-ecological practices in ICT equipment management in Poland, which is a valuable basis for the recommendation of sustainable development policy.

3. Results

First, the data collected from the Central Statistical Office were analyzed. The variables X1-X5 are specified in relation to the NUTS-2 regions in Poland (Table 1). These data show significant variation between regions. The Warsaw Capital Region is distinguished by the highest values for most indicators, which may be related to the developed technological infrastructure, high level of investment in new technologies and greater environmental awareness among companies operating in the capital. The values for this region in terms of reducing paper printing (61.1%), reducing energy consumption (45.4%), and taking environmental aspects into account when choosing equipment (67.8%) are among the highest in the country. The percentage of companies handing over or returning waste ICT equipment also stands out in particular, at 34.7%, the highest rate in the entire analysis.

Table 1.

Share of enterprises using pro-ecological solutions in the area of ICT equipment use by NUTS-2 regions in Poland in 2022

NUTS-2 region	X1	X2	X3	X4	X5
Dolnośląskie	57.4	43.3	63.4	70.2	24.4
Kujawsko-pomorskie	53.2	44.0	62.3	68.8	19.5
Lubelskie	52.9	42.7	59.4	67.8	19.3
Lubuskie	50.2	37.6	60.3	62.5	21.7
Łódzkie	51.0	43.3	62.8	67.3	18.4
Małopolskie	57.3	44.8	61.5	67.7	23.1
Warszawski Stołeczny	61.1	45.4	67.8	71.1	34.7
Mazowiecki Regionalny	51.7	39.0	63.2	66.7	16.9
Opolskie	52.4	41.3	63.6	71.6	24.0
Podkarpackie	53.8	42.6	63.3	70.0	17.0
Podlaskie	52.3	38.8	66.4	69.7	17.5
Pomorskie	55.4	43.0	64.0	75.1	21.4
Śląskie	55.4	42.5	66.4	70.0	23.3
Świętokrzyskie	51.6	41.3	66.4	65.4	16.6
Warmińsko-mazurskie	51.8	43.9	65.8	70.5	17.4
Wielkopolskie	54.9	44.2	63.8	68.7	22.0
Zachodniopomorskie	53.7	41.5	64.8	70.5	21.1

Note. X1 - share of enterprises reducing paper printing, X2 - share of enterprises reducing energy consumption of ICT equipment, X3 - percentage of companies taking into account environmental protection when choosing ICT equipment, X4 - share of enterprises returning waste equipment to appropriate collection points, X5 - percentage of companies selling, donating to charity or returning to the lessor.

Source: own elaboration based on [GUS].

On the other hand, regions such as Lubuskie, Świętokrzyskie and Mazowiecki Regionalny are characterized by lower values for most variables, which may be the result of weaker economic infrastructure, lower expenditure on innovation and a smaller number of large enterprises, which often lead in the implementation of pro-ecological solutions. For example, in Lubuskie only 50.2% of companies declare reducing paper printing, and 37.6% reduce energy consumption by ICT equipment, which places this region at the bottom of the list.

It can also be noted that regions such as Małopolska and Lower Silesia, although they do not reach the Warsaw levels, show relatively high rates of implementation of pro-ecological practices. Lower Silesia, on the other hand, is characterized by a 57.4% share of companies limiting paper printing and a 63.4% share of companies taking into account environmental issues when choosing ICT equipment, which may indicate well-developed structures supporting sustainable development and the presence of numerous technology companies that invest in ecological solutions. Northern regions such as Pomerania and West Pomerania are also interesting. In the Pomeranian Voivodeship, the percentage of enterprises returning waste equipment to appropriate collection points is 75.1%, which indicates a very high awareness of ICT equipment recycling. Such practices can be supported by well-developed waste management systems and regional policies that promote environmental protection.

To sum up, the level of implementation of the specified pro-ecological practices in enterprises varies and depends on local economic conditions and the degree of development of technological infrastructure. Regions with a higher level of development, such as the Warsaw Capital Region or Lower Silesia, perform better in implementing sustainable ICT practices, while less developed regions, such as Lubuskie or Mazowiecki Regional, lag behind.

Then, measures of development for the studied regions were calculated and a ranking was made, ordering them in descending order. The results are presented in Table 2.

Table 2.

Ranking according to the measure of development of NUTS-2 regions in the implementation of pro-ecological solutions in the area of the use of ICT equipment

NUTS-2 region	Distance from pattern	Measure of development	Ranking
Warszawski Stołeczny	1.484	0.982	1
Dolnośląskie	4.002	0.953	2
Śląskie	4.181	0.950	3
Pomorskie	4.297	0.949	4
Wielkopolskie	4.839	0.943	5
Małopolskie	5.021	0.941	6
Opolskie	5.078	0.940	7
Zachodniopomorskie	5.087	0.940	8
Warmińsko-mazurskie	5.707	0.932	9
Kujawsko-pomorskie	5.781	0.932	10
Podkarpackie	5.837	0.931	11
Podlaskie	6.412	0.924	12
Łódzkie	6.568	0.922	13
Lubelskie	6.769	0.920	14
Świętokrzyskie	6.895	0.918	15
Mazowiecki Regionalny	7.270	0.914	16
Lubuskie	8.529	0.899	17

Source: own study.

The first place in the ranking is taken by the Warsaw Capital Region, which achieves the highest value of the measure of development (0.982) and the lowest distance from the standard (1.484). The region's high score is in line with its strong economic position, high level of urbanization, and access to resources and technologies to support green activities. Companies

in the region are better able to implement innovative and sustainable practices, which translates into high environmental performance. Lower Silesia and Silesia, occupying the second and third place in the ranking, respectively, are also characterized by high values of the measure of development, amounting to 0.953 and 0.950. These regions are known for their booming industrial and technological sectors, which is conducive to investment in solutions that reduce environmental impact. A strong industrial base in Silesia, combined with an increasing focus on the ecological transition, contributes to achieving relatively high results in the area of sustainable use of ICT. Regions such as Pomerania, Greater Poland and Lesser Poland are at the top of the ranking, with measures of development of 0.949, 0.943 and 0.941 respectively. Pomerania, for example, is well positioned thanks to its well-developed recycling infrastructure and strong commitment to environmental activities supported by regional policy. Wielkopolska and Małopolska also show high activity in the implementation of ecological practices, which may result from the presence of numerous innovative enterprises. At the end of the ranking are the following regions: Mazowiecki Regionalny and Lubuskie, which achieve the lowest measures of development (0.914 and 0.899, respectively) and the highest distances from the standard (7.270 and 8.529). The low results of these regions indicate the need to increase investment in pro-ecological solutions and to raise environmental awareness among local enterprises. The Mazovian Regional Region, despite its proximity to the capital area, shows significant shortcomings in the implementation of sustainable practices.

4. Conclusion

This study provides important information on the spatial differentiation of the implementation of pro-ecological ICT practices in Polish enterprises, broken down by NUTS-2 regions. The main objective of the study was to identify regional differences and rank administrative units in terms of the level of sustainable management of ICT equipment. This goal was achieved through the use of multivariate statistical analysis methods, which allowed comprehensive conclusions to be drawn.

The results indicate that the Warsaw Capital Region is distinguished by the highest level of implementation of pro-ecological solutions, which reflects its developed technological infrastructure and high environmental awareness of enterprises. The Lower Silesia and Silesian regions also achieved high values of the measure of development, which can be linked to dynamically developing industrial sectors and investments in ecological innovations. On the other hand, regions such as Mazowiecki Regionalny and Lubuskie are at the bottom of the ranking, indicating the need to intensify pro-ecological activities and greater support in the field of ecological infrastructure.

The research hypotheses were positively verified. Significant regional differences in the implementation of sustainable practices have been confirmed and it has been shown that a higher level of economic development of the region correlates with more frequent implementation of pro-ecological activities.

However, despite the achievement of the research goal, some limitations can be identified in this study. First, the research involves the use of data from one year, which does not allow for the analysis of long-term trends. In addition, the variables used may not fully reflect the complexity of the phenomenon of implementing pro-ecological practices. Future research should take into account long-term data and additional factors such as regional policies, implementation barriers and environmental awareness. It is also worth considering international comparisons to assess how Polish regions compare to other countries in terms of sustainable management of ICT equipment in enterprises.

References

1. Anuradha, C.A. (2024). A Conceptual Level on Green Computing Applications on Eco-Friendly Approaches. *Int. J. Sci. Res. Comput. Sci. Eng. Inf. Technol.*, Vol. 10, Iss. 5, pp. 756-761. doi: 10.32628/CSEIT2410433.
2. Bieser, J., Hilty, L. (2018). Indirect Effects of the Digital Transformation on Environmental Sustainability: Methodological Challenges in Assessing the Greenhouse Gas Abatement Potential of ICT. *EPiC Series in Computing*, Vol. 52, pp. 68-81, doi: 10.29007/lx7q.
3. Bull, R. (2015). ICT as an enabler for sustainable development: reflections on opportunities and barriers. *Journal of Information, Communication and Ethics in Society*, Vol. 13 Iss. 1, pp. 19-23, doi: 10.1108/JICES-12-2014-0061.
4. Charfeddine, L., Umlai, M. (2023). ICT sector, digitization and environmental sustainability: A systematic review of the literature from 2000 to 2022. *Renewable and Sustainable Energy Reviews*, Vol. 184, p. 113482, doi: 10.1016/j.rser.2023.113482.
5. Coutaz, J., Carlesso, A., Bonnefond, N., Balzarini, R., Laurillau, Y., Mandran, N., Crowley, J. (2018). "Will the Last One Out, Please Turn off the Lights": Promoting Energy Awareness in Public Areas of Office Buildings. 14th European Conference, AmI 2018, Larnaca, Cyprus, November 12-14, 2018, Proceedings. doi: 10.1007/978-3-030-03062-9_2.
6. Friege, H., Oberdörfer, M., Günther, M. (2015). Optimising Waste From Electric and Electronic Equipment Collection Systems: A Comparison of Approaches in European Countries. *Waste management & research: the journal of the International Solid Wastes and Public Cleansing Association, ISWA*, 33. Doi: 10.1177/0734242X14567500.
7. Kamilaris, A., Pantazaras, A., Kalluri, B., Kondepudi, S., Tham, K., Dang, J. (2014). Good Practices in the Use of ICT Equipment for Electricity Savings at a University Campus.

- International Green Computing Conference, IGCC 2014.* doi: 10.1109/IGCC.2014.7039176.
8. Kaszyński, P., Benalcazar, P., Pałka, P., Rój, R., Malec, M. (2021). Optimal Location-Allocation of Printing Devices for Energy Saving Using a Novel MILP Approach. *Energies*, Vol. 14, p. 6353. doi: 10.3390/en14196353.
 9. Lu, B., Yang, J., Ijomah, W., Wu, W., Zlamparet, G. (2017). Perspectives on reuse of WEEE in China: Lessons from the EU. *Resources. Conservation and Recycling*, 135. Doi: 10.1016/j.resconrec.2017.07.012.
 10. Mesjasz-Lech, A. (2018). *Educational and research potential of regions and the innovativeness of businesses - an analysis of spatial concentration*. Valenzia: IA TED Academy, pp. 4425-4432.
 11. Seroka-Stolka, O. (2012). Analiza wybranych czynników determinujących poziom świadomości ekologicznej przyszłych menedżerów. *Ekonomia i Środowisko*, Vol. 1, pp. 245-261.
 12. Siddiqui, J., Samad, A., Khan, Z.A. (2014). Study and Approaches to Green Environment through Eco- Friendly Devices. *International Journal of Computer Science and Mobile Computing*, Vol. 3, Iss. 5, pp. 382-388.
 13. Suleri, J. (2018). Pro-environmental Printing Behaviour as an Indicator to Reduce Paper Cost at Work. *European Journal of Sustainable Development Research*, 2(3), 38. doi: 10.20897/ejosdr/2670.
 14. Suleri, J., Cavagnaro, E. (2016). Promoting Pro-environmental Printing Behavior: The Role of ICT Barriers and Sustainable Values. *Dutch Journal of Finance and Management*, Vol. 1. doi: 10.20897/lectito.201638.
 15. Wysocki, J. (2016). Strategic approach to proecological activities of companies. *European Journal of Service Management*, Vol. 18, pp. 63-69. Doi: 10.18276/ejsm.2016.18-08.
 16. Zawada, M. (2009). Zastosowanie wybranych metod wielowymiarowej Analizy statystycznej w procesie inwestowania na rynku kapitałowym w Polsce. In: A. Mesjasz-Lech (ed.), *Nowoczesne Instrumenty Zarządzania*. Częstochowa: Sekcja Wydawnictw Wydziału Zarządzania Politechniki Częstochowskiej, p. 78.

EVOLVING ROLE AND PERFORMANCE OF SCIENCE AND TECHNOLOGY PARKS IN INNOVATION SYSTEMS: A QUINTUPLE HELIX PERSPECTIVE

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Purpose: The purpose of the study was to identify various dimensions of change within science and technology parks over a ten-year period. This study identifies how science and technology parks have changed between 2012-2022 and whether they align with the Quintuple Helix system.

Design/methodology/approach: The primary research method employed is document analysis, supplemented by comparative analysis as the principal research technique. This study utilizes secondary data sourced from the International Association of Science and technology parks and Areas of Innovation (IASP).

Findings: The study illustrates that between 2012 and 2022, science and technology parks have experienced an increased presence of the private sector within their ownership structures. Furthermore, these parks have transitioned from facilities management organizations to entities that collect, process, and disseminate knowledge to their clients through value-added services. They have begun to provide support to non-resident companies, underscoring their expanded role within the innovation ecosystem. In alignment with the Quintuple Helix model, science and technology parks facilitate collaboration among academia, industry, government, civil society, and the natural environment. They are increasingly involved in community support and sustainability initiatives. These developments highlight the parks' pivotal role in orchestrating regional innovation systems and enhancing regional competitiveness.

Research limitations/implications: One limitation of this study is the reliance on secondary data, coupled with the limited availability of data regarding the number of parks and the geographical distribution of the sample. This may result in a sample that is not representative of each region. Future research should aim to explore additional variables and strive for a more balanced sample distribution across all geographical regions.

Practical implications: The findings suggest that science and technology parks should enhance investment strategies to attract private sector involvement, diversify their service offerings to include more knowledge-based and value-added services, and develop tools to support non-resident companies. Policymakers can use these insights to craft policies that encourage private sector investment in science and technology parks, fostering a more dynamic and diverse ownership structure.

Social implications: Increased community engagement can amplify the social impact of science and technology parks. The emphasis on community engagement and sustainability initiatives can enhance the quality of life for local residents, promote social cohesion, and encourage environmentally responsible practices. Parks can also serve as hubs for

education and social services, further integrating themselves into the fabric of the community and contributing to overall social well-being.

Originality/value: The paper presents novel insights regarding the evolving ownership structures of science and technology parks and provides empirical evidence supporting the shift from their traditional role in property management to a focus on knowledge creation. This knowledge is disseminated through various value-added services to resident companies and a wider public which enhance the parks' role in the innovation ecosystem.

Keywords: science and technology parks, Quintuple Helix, innovation systems, value-added services.

Category of the paper: research paper.

1. Introduction

To Innovation plays a crucial role in regional economic growth, a topic widely discussed from both economic and political perspectives (Maradana, 2017; Shpak, Ruduyk, 2023). Science and technology parks in contemporary knowledge-based economies align well with both economic and political objectives. These entities attract early-stage entrepreneurs, researchers, investors, and other institutions, catalyzing multidirectional knowledge transfer, innovation collaboration, and co-creation, leading to the development of regional innovation ecosystems based on cooperation. Besides providing space for business development, including research, experiments, tests, and prototypes, the value-added of such spaces lies in offering a wide range of services, opportunities for interaction and networking. As a consequence of interactions within science and technology parks, resident companies accrue benefits from their geographical proximity to other innovative entities, access to specialized knowledge and support systems, availability of funding opportunities, and enhanced reputational standing (Sanz et al., 2023).

Science and technology parks offer various types of value-added support, primarily targeting nascent, innovative enterprises engaged in the development of new products or services, market entry, or business acceleration. The concept of science and technology parks initiated the development of innovation support spaces and initiatives of various kind. The inception of innovation support spaces. While these parks continue to play a pivotal role as innovation support entities, the innovation ecosystem has expanded to include other key institutions within the helix system, such as clusters, business incubators, accelerators, innovation districts, industrial campuses, areas of innovation and living labs. These spaces differ conceptually but share the primary goal of supporting innovation to enhance regional competitiveness. This article focuses on 'science and technology parks', also known in literature and practice as 'science and technology parks', 'technology parks', 'technopoles' and research parks (Waligóra, 2015). All these entities fit the definition of science and technology parks. They provide space and value-added services which support innovation development and

consequently contribute to local and national economies. The scope of activities and ownership structures of these entities vary depending on the specific contexts and economic conditions of the region in which the science park and technology park operates. Diversity in ownership structures and stakeholder influence often leads to different priorities and management strategies, affecting the dynamics of relationships developed at each level of Quintuple Helix.

Science and technology parks play a crucial role in developing innovative regional environments. Davies (2013) suggests that parks ‘orchestrate’ collaboration within regional innovation systems. These are places where businesses, the public sector, and research and development institutions collaborate to create and implement new ideas and technologies. Relationships within such parks are vital as they facilitate the organization and exchange of knowledge, resources, and experiences among various entities (private sector, public sector, and academia), which are the fundamental building blocks of innovation systems based on the triple helix concept (Etzkowitz, 2008). In 2009, Carayannis and Campbell added the civil society as the fourth element of the helix, and in 2012, they included the natural environment as the fifth dimension. Nordberg (2015) critically addressed this extension of the helix structure, indicating that society and citizens are merely the backdrop against which innovation processes occur. However, for science and technology parks it is important to support and enhance the creation of innovations for and with civil society or for the benefit of the natural environment. By engaging in a wide variety of activities and with various stakeholders, science and technology parks play an important role as ‘orchestrators’ of relationships among different stakeholders that fit into the Quintuple Helix (Sousa, Silva, Celani, 2023).

2. Methodology

The purpose of the study was to identify various dimensions of change within science and technology parks over a ten-year period. This study identifies how science and technology parks have changed between 2012-2022 and whether they align with the Quintuple Helix system. The research questions have been designed as follows:

- Has the ownership model of science and technology parks changed over a ten-year period?
- How have the key activities and functions of science and technology parks changed over a ten-year period?
- Do science and technology parks’ activities align with Quintuple Helix model, which encompasses interactions among academia, industry, government, civil society, and the natural environment

The primary research method employed is document analysis, supplemented by comparative analysis as the principal research technique. This study utilizes secondary data sourced from the International Association of Science and technology parks and Areas of Innovation (IASP) Global Surveys conducted in 2012 (based on the research sample of 119 science and technology parks from 38 countries) and 2022 (based on the research sample of 113 science and technology parks from 47 countries). IASP, established in 1984, is a globally recognized organization headquartered in Malaga, Spain. It comprises nearly 400 members (science and technology parks and areas of innovation), including science and technology parks and areas of innovation, spanning 80 countries across all continents¹. This extensive global presence facilitates a diverse exchange of knowledge and best practice among science and technology parks and innovation districts worldwide.

3. Results

The concept of science and technology parks has undergone significant evolution over the past five decades. As these institutions have developed, the stakeholders involved and the dynamics of forces and influences within science and technology parks have shifted, leading to the emergence of diverse business models. The initial park initiatives in the 1950s were experimental in nature, rather than being well-defined instruments of innovation policy (Charles, Uyarra, 2010). The first science park was established by Stanford University in 1951, followed by the creation of Research Triangle Park in 1959 in the United States. This concept rapidly gained global traction. In Europe, the first science park, Sophia Antipolis, was established in France in 1969, followed by the Cambridge Science Park in the United Kingdom. During the 1980s and 1990s, science and technology parks began to be recognized as vital tools for fostering economic and technological growth. In Europe, the science park movement gained prominence in the mid-1980s, with the majority of existing parks being established in the 1990s and beyond.

Over a decade, several trends have emerged within science and technology parks, particularly concerning ownership models. Initially, the majority of science and technology parks were publicly owned. Although public ownership remains predominant globally, the private sector has become increasingly prominent within ownership structures. In 2022, 50.4% of science and technology parks reported being fully owned by the public sector, a slight decrease from 54.6% in 2012. Conversely, 22.1% of science and technology parks globally were privately owned in 2022, up from 16% in 2012. Additionally, mixed ownership models were reported by 27.4% of science and technology parks in 2022, compared to 29.4% in 2012.

¹ Source: <https://www.iasp.ws/our-members/directory>: 13.10.2024.

While many science and technology parks globally are publicly owned and retain their ownership structure throughout their life cycle, there are numerous instances of parks that have altered their ownership model. Several mature science and technology parks have transitioned to private ownership, including Cambridge Science Park and Manchester Science Park in the UK, and Sophia Antipolis in France. These changes in ownership structures frequently modify the relationships and dynamics among stakeholders.

Furthermore, significant variations of ownership models exist across different geographical regions. Mixed ownership models are predominant in Africa, North America, and Europe. In contrast, privately owned science and technology parks are most prevalent in the Asia-Pacific and Latin America regions. The model of full public sector ownership remains the most common in Eurasia, as well as in West Asia and North Africa.

Also, public involvement in science and technology parks can be achieved through various channels beyond ownership models. Governments and public institutions can provide critical support by offering access to funding and financing specific projects within the parks. Additionally, public sector representatives can play influential roles by serving as members of the board of directors or advisory boards, thereby contributing to strategic decision-making and governance. These forms of engagement ensure that public interests are represented and that science and technology parks benefit from a diverse range of expertise and resources, fostering an environment conducive to innovation and growth.

Another discernible trend within the science park concept is the evolving role of management teams in service provision. Management teams at science and technology parks are increasingly shifting their focus away from facilities management. In 2022, 67.3% of science and technology parks were engaged in facilities management, compared to 71.4% in 2012. Some science and technology parks outsourced their property management activities (e.g. Mjardevi Science Park in Sweden, Z-Park in China or 22@Barcelona in Spain). Instead of being preoccupied with facilities management, there is a growing emphasis on the provision of 'value-added' services by managers of science and technology parks. These knowledge-based services encompass a wide range of support designed to foster interaction and establish relationships with various stakeholders within the innovation ecosystem. These services included in 2022 for instance: incubation and acceleration (79.6% of science and technology parks globally in 2022), events for residents (78.8%) and open public (57.5%), community building (77.9%), financial planning (57.5%), technology transfer (57.5%), investor relations (54%), talent acquisition (54%), strategic and business planning (66.4%), etc. It is noteworthy that access to knowledge-based services provided by science and technology parks extends to external companies. In 2022, a mere 15.9% of IASP science and technology parks restricted their knowledge-based services exclusively to resident companies. Conversely, a significantly larger proportion of respondents (46.9% and 37.2%) offered these services to non-resident companies, either under varying or identical conditions.

Although it has been observed that between 2012 and 2022 science and technology parks have developed more specialized support services, there has been a noticeable decline in their focus on providing international support. In 2022, 77% of science and technology parks globally offered support related to international relations building and networking, compared to 86.6% in 2012. Instead, there has been more pressure for science park management to enhance activities also for the benefit of local communities and natural environment. Consequently, an increasing number of science and technology parks have undertaken initiatives aimed at promoting sustainable development and eco-friendly solutions. These efforts often extend to active engagement with civil society, including the organization of events for educational institutions, charitable organizations, and unemployed individuals. There has been a notable increase in the provision of health, education, and social services within science and technology parks, available both to resident companies and the general public. In 2022, 57.3% of science and technology parks globally reported having these elements on their sites. In the 2022 IASP Global Survey, data pertaining to ‘community’ building was gathered for the first time, indicating that this aspect had previously been a minor focus within science and technology parks.”

The above examples underscore the commitment of science and technology parks to fostering community engagement and contributing to the well-being of local populations.

4. Discussion

The study illustrates that between 2012 and 2022, science and technology parks have witnessed a significant increase in private sector involvement within their ownership structures. This trend indicates that these parks have evolved into viable and profitable entities for private sector investment. The concept has gained credibility, and the private sector recognizes the advantages of investing in and supporting such developments. The findings indicate that science and technology parks should meticulously evaluate their investment strategies to attract private sector involvement, ensuring that this does not compromise their primary objectives. It is crucial to maintain a balance, as the overarching goals of the parks may shift if the private sector assumes a dominant role.

The study highlights the science and technology park transformation, moving from property management to organizations focused on provision of sophisticated knowledge-based services. In addition to implementing green solutions and spaces, workshops and events promoting sustainable development and eco-friendly practices are organized for resident companies and the local community. Firms are encouraged to use renewable energy sources, reduce waste, and implement sustainable solutions. Collective efforts towards environmental

protection foster a culture of ecological responsibility, benefiting both the local community and the entire region.

The transition from property management organizations to more advanced entities is also evident in the evolving definitions of science and technology provided by science park associations: United Kingdom Association of Science and technology parks, Association of University Research Parks (US) and International Association of Science and technology parks (Table 1).

Table 1.
Definitions of science and technology parks

Organization	Definition (Early)	Definition (Current)
United Kingdom Science Park Association	1990s-2000s: A property-based initiative linked to universities, aimed at fostering collaboration between academia and industry, providing space and resources for R&D activities.	2020s: A science park is a business support and technology transfer initiative that: • encourages and supports start-up and incubation of innovation-led, high-growth knowledge-based businesses; • provides an environment where larger and international businesses can develop specific and close interactions with a particular centre of knowledge creation for their mutual benefit; • has formal and operational links with centres of knowledge creation such as universities, higher education institutes and research organisations.
Association Of University Research Park (US)	1990s-2000s: Developments affiliated with universities, focused on providing space for research and development activities.	2020s: Developments that foster innovation and commercialization of technology through the support of research and development. These parks are typically affiliated with universities and aim to create environments that support the growth of technology-based companies.

Cont. table 1.

International Association Of Science And Technology Parks	1990s-2000s: Organizations managed by professionals whose main aim is to increase the wealth of their community by promoting innovation and competitiveness among associated businesses and knowledge-based institutions. This includes managing the flow of knowledge and technology among universities, R&D institutions, companies, and markets, and facilitating innovation-based companies through incubation and spin-off processes; and provide other added-value services together with high-quality space and facilities.	2020s: Areas of innovation, of which science, technology and research parks are highly specialized type, play a key role in the economic development of their environment. Through a dynamic and innovation mix of policies, programs, quality space and facilities and high value-added services, they: • stimulate and manage the flow of knowledge and technology between universities and companies, • facilitate the communication between companies, entrepreneurs and technicians, • provide environments that enhance a culture of innovation, creativity and quality, • focus on companies and research institutions as well as on people: the entrepreneurs and 'knowledge workers', • facilitate the creation of new businesses via incubation and spin-off mechanisms, and accelerate the growth of small and medium size companies • work in a global network that gathers many thousands of innovative companies and research institutions throughout the world, facilitating the internationalization of their resident companies.

Source: own work.

The above definitions of a science and technology parks do no longer focus on the quality spaces and facility management but on stakeholders' interaction and provision of value-added services based on knowledge.

Modern science and technology parks organizations focus on knowledge creation i.e. they collect, process, and disseminate information to their clients, which is one of the key characteristics of knowledge-based organizations. Moreover, the provision of specialized knowledge-based services extends beyond resident companies to include non-resident companies, indicating the broader impact and recognition of SPs as crucial players in regional innovation systems.

Davies (2013) names that evolution a "shift from third generation science and technology parks to areas of innovation" (p.3) where innovation support is available beyond physical boundaries and is not only available to businesses but also local communities benefit from their presence in the innovation ecosystem. The value-added services make science and technology parks quite unique on the market (Lecluyse, Knockaert, Spithoven, 2019).

Ratinho and Henriques (2010) elaborate that the knowledge possessed by park management is multidisciplinary, integrating scientific, technical, business, and political knowledge. This multidisciplinary approach enables managers to produce high-quality services tailored to the specific needs of client companies. The knowledge production within modern science and technology parks is a blend of tacit knowledge (skills, know-how, and personal attributes) and explicit knowledge (experience and facts that can be easily transmitted).

The process of knowledge creation within science and technology parks involves both individual and collective efforts. Managers draw on their personal experiences to generate new knowledge, which they then process and disseminate to client companies (Campanella, Peruta, Giudice, 2014). Science and technology management teams often work independently, in teams, or in collaboration with other professionals to create new knowledge or enhance the value of existing knowledge for their clients.

The implications of this shift are profound. The transformation of science and technology parks from property management organizations to knowledge-based organizations represents a significant development in the landscape of regional innovation systems. They are considered to be 'knowledge territories' (Sousa, Silva, Celani, 2023). This shift underscores the importance of knowledge creation and dissemination in driving economic growth and innovation, highlighting the evolving role of science and technology parks as key facilitators of knowledge-based economies.

Moreover, the emphasis on knowledge creation and dissemination fosters a culture of continuous learning and improvement within science and technology parks. This culture is vital for sustaining long-term growth and ensuring that parks remain at the forefront of technological and business advancements. By leveraging both tacit and explicit knowledge, park managers can create a dynamic environment that encourages collaboration, creativity, and the exchange of ideas. This environment not only benefits the resident companies but also attracts new businesses and talent to the region, further strengthening the regional innovation system.

To summarize, the park transformation underscores the critical role of knowledge creation and dissemination in driving sustainable development and economic growth. By providing a wide range of value-added services science and technology parks make innovations and business adventures more probable boosting the overall competitiveness and resilience of the regions they serve. This holistic approach ensures that innovation support transcends physical boundaries, benefiting businesses, local communities, and the environment. Consequently, science and technology parks reinforce the Quintuple Helix framework's emphasis on sustainability and societal impact, fostering a dynamic and inclusive innovation landscape.

5. Summary

This study investigated the evolution of science and technology parks over the past decade, focusing on changes in ownership models, key activities, functions and alignment with the Quintuple Helix model. Over the past decade, the ownership models of science and technology parks have shifted significantly. Initially, most science and technology parks were publicly owned. However, there has been a noticeable increase in private sector involvement. The proportion of privately owned parks has risen, while public ownership has slightly decreased. Mixed ownership models have also seen a minor decline, indicating a trend towards more diverse and dynamic ownership structures. This shift reflects the growing role of the private sector in the management and strategic direction of science and technology parks.

The key activities and functions of science and technology parks have evolved from a primary focus on facilities management to the provision of knowledge-based services. There has been a significant increase in services such as incubation and acceleration, community building, and technology transfer. Additionally, science and technology parks have expanded their support to non-resident companies, highlighting their broader role in the innovation ecosystem. This shift underscores the transition of science and technology parks from property management entities to knowledge-based organizations.

The activities of science and technology parks increasingly align with the Quintuple Helix model, which includes interactions among academia, industry, government, civil society, and the natural environment. Science and technology parks act as orchestrators of these relationships, fostering collaboration and innovation. They have enhanced their focus on community engagement and environmental sustainability, with many parks providing health, education, and social services. This alignment underscores the role of science and technology parks in driving sustainable development and regional competitiveness.

To summarize, the study highlights the dynamic changes in ownership models, the evolution of key activities, and the alignment of science and technology parks with the Quintuple Helix model over a ten-year period. These transformations reflect the adaptation of science and technology parks to the demands of knowledge-based economies, emphasizing their importance in fostering innovation and regional growth.

While the study provides valuable insights, it also has limitations, such as its reliance on secondary data and the limited availability of information on the number and geographical distribution of parks, which may lead to a non-representative sample. Future research should consider additional variables and strive for a more balanced sample distribution. On a practical level, the findings suggest that science and technology parks should improve their investment strategies to attract private sector involvement, diversify their service offerings to include more knowledge-based and value-added services, and develop tools to support non-resident companies.

References

1. Campanella, F., Peruta, M., Giudice, M. (2014). Creating conditions for innovative performance of science and technology parks in Europe. How manage the intellectual capital for converting knowledge into organizational action. *Journal of Intellectual Capital*.
2. Carayannis, E.G., Campbell, D.F.J. (2009). 'Mode 3' and 'Quadruple Helix': toward a 21st century fractal innovation ecosystem. *International Journal of Technology Management*, 46(3/4), 201-234.
3. Charles, D., Uyarra, E. (2010). *Practical Benefits of Innovation-related Instruments at Regional and Local Level*. Report for the EU-oecd Innovation Project. A New Innovation Strategy for Regions. Paris: OECD.
4. Davies, J. (2013). *From Third Generation Science and technology parks to Areas of Innovation*. 30th IASP World Conference on Science and Technology Parks, Recife, Brazil.
5. Etzkowitz, H. (2008). *The Triple Helix: University-Industry-Government Innovation in Action*. Routledge.
6. IASP (2012). International Association of Science and technology parks 2012 Global Survey, IASP.
7. IASP (2022) International Association of Science and technology parks 2012 Global Survey, IASP.
8. Lecluyse, L., Knockaert, M., Spithoven, A. (2019). The contribution of science and technology parks: a literature review and future research agenda. *The Journal of Technology Transfer*, 44, 559-595.
9. Maradana, R.P., Pradhan, R.P., Dash, S. (2017). Does innovation promote economic growth? Evidence from European countries. *J. Innov. Entrep.*, 6, 1.
10. Nordberg, D. (2015). *Corporate governance: Principles and issues*. SAGE Publications.
11. Ratinho, T., Henriques, E. (2010) The role of science and technology parks and business incubators in converging countries: Evidence from Portugal. *Technovation*, 30, pp. 278-290.
12. Sanz, L., Klofsten, M., Van Dinteren, J., Jansen, P. (2023). *A Taxonomy of Organised Innovation Spaces*. Battiston, A., Fazio, A. (eds.). Luxembourg: Publications Office of the European Union.
13. Shpak, Y., Ruduyk, Y. (2023). *The role and impact of innovative development on the economic growth of countries*. Economic Scope.
14. Sousa, M., Silva, R., Celani, G. (2023). Placemaking in the Design of Knowledge-Based Urban Developments. *Joelho Revista de Cultura Arquitectonica*.
15. Waligóra, K. (2015). Parki naukowe, technologiczne i przemysłowe jako narzędzie wspierające potencjał innowacyjny polskiej gospodarki. In: E. Gruszewska (ed.), *Współczesne wyzwania rozwoju gospodarczego: polityka i kreacja potencjału: kreacja, innowacyjność, handel zagraniczny, Cz. 1* (pp. 171-186). Białystok: Wydawnictwo Uniwersytetu w Białymstoku.

MULTI-DIMENSIONAL SYSTEMIC RISK MEASURE UNDER EXOGENOUS SHOCKS INCLUDING CLIMATE CHANGE

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Purpose: This study develops a novel methodology for measuring systemic risk through a multidimensional approach, focusing on the impact of exogenous factors. By identifying systemic risk and analysing individual risk factors, we aim to provide a more comprehensive understanding of vulnerabilities in the financial sector.

Design/methodology/approach: We use econometric models to assess systemic risk, applying our method to eight systemically important financial institutions in Poland between 2005 and 2023. Our analysis covers various risk factors, including climate risk, stock market fluctuations, and interbank liquidity, enabling both isolated and overall assessment of the impact of exogenous shocks on the system.

Findings: Our results show that climate risk is becoming increasingly significant, particularly in light of recent crises such as the COVID-19 pandemic and Russia's invasion of Ukraine. We also observe an increase in systemic risk during specific periods (2008-2009 and 2011-2013), with the impact of individual shocks varying.

Research limitations/implications: Our results highlight the need for sophisticated, multidimensional analyses of systemic risk to enhance the resilience of financial systems against diverse shocks.

Practical implications: This research contributes to the existing literature by offering a universal framework for assessing systemic risk that aggregates multiple exogenous factors, particularly emphasizing the often-overlooked role of climate risk.

Social implications: The research provides a framework for identifying systemic risks, including climate-related vulnerabilities, enabling policymakers to enhance the resilience of financial systems and protect societal stability against diverse economic and environmental shocks.

Originality/value: Importantly, we are the first to combine transition risk indicated by stranded assets with physical risk, measured by temperature deviations from the multi-year average, in the assessment of Polish systemic climate risk.

Keywords: climate risk, financial stability, systemic risk, liquidity risk.

Category of the paper: research paper.

JEL Classification: G20, Q54, C53.

1. Introduction

Systemic risk, despite its relevance to understanding financial stability, has so far not received a single, universally accepted definition. Initially, the idea (and definition) of systemic risk was associated exclusively with the financial sector, which was related to the fact that most of the crises of the 1990s originated in banks. Systemic risk was then understood as the possibility of a collapse of the (financial) system due to the failure of key financial institutions (Li et al., 2021). At the same time, the complexity of the nature of systemic risk, the interdependencies between different elements of the system, and the possible consequences in the form of a domino effect, contagion to other markets, were noticed, thus posing a significant threat to financial stability (Klinke, Renn, 2002; Renn et al., 2018).

The 2007-2009 subprime crisis and the collapse of Lehman Brothers fundamentally reshaped the understanding of systemic risk. In response, the IMF (2009) recommended analysing multiple sources of risk to obtain a more comprehensive view of potential threats. Comparative studies, including those by the European Central Bank (ECB 2010), defined systemic risk as the risk of a significant event (shock) that propagates through interconnected institutions, leading to instability across the entire system. These shocks can be either endogenous, originating within the financial system, or exogenous, caused by external factors. This dual nature further complicates efforts to consistently define and measure systemic risk.

Building on existing definitions of systemic risk, Smaga (2014), along with Montagna et al. (2020), Freixas et al. (2023), and Undheim (2024), identified several key characteristics that should be considered when developing a systemic risk measure:

- Systemic risk affects a significant portion of the financial system, making it essential to monitor critical elements, such as systemically important financial institutions (SIFIs, O-SIIs).
- Systemic risk is the effect of shocks that can originate from both endogenous (within the system) and exogenous (external) sources.
- The occurrence of shocks leading to the instability of institutions (system) requires the examination of the sensitivity of these institutions (system) to potential shocks.
- Systemic risk is characterized by the contagion effect, through which it materializes and spreads in the financial system. The pace and scale of this transmission exceeds the values that could be expected under normal market conditions (domino effect).
- The nature of systemic risk is multidimensional, requiring a comprehensive approach to measurement and management.

Defining systemic risk is further complicated by emerging challenges such as climate change. Climate risk, which includes both physical risks from environmental changes and transition risks linked to the shift towards a low-carbon economy, has become a critical component in discussions of systemic risk (BCBS, 2021; ESRB, 2021, 2022). The potential

impact of climate shocks on the stability of financial markets and institutions was highlighted by Mark Carney, who emphasized the urgent need for the financial sector to incorporate climate risk into a comprehensive systemic risk framework (Carney, 2015). The effects of climate change were further amplified by the COVID-19 pandemic (Hepburn et al., 2020), accelerating the inclusion of climate risk in systemic risk measurement processes (Jung et al., 2023, Jourde, Moreau, 2024). The absence of a unified definition of systemic risk also arises from the varying perspectives of different stakeholders. Regulators primarily emphasize its potential to cause economic disruption, while market participants are more concerned with its effects on asset prices and market liquidity (Benoit et al., 2017; Giglio et al., 2021; Nguyen et al., 2023).

To address these challenges, and in line with Foglia & Angelini (2021), Hochrainer-Stigler et al. (2023), and Chen et al. (2023) we propose viewing systemic risk as a multidimensional concept that requires a comprehensive and nuanced approach to measurement. By including a broader spectrum of external risks that can contribute to systemic events – such as market (equity) shocks, climate-related risks and interbank liquidity dynamics, this approach provides an alternative tool for monitoring and managing complex financial stability risks at the systemic level. The inclusion of climate risk, including both transition and physical aspects, is particularly important as it represents an often underestimated and growing dimension of systemic risk with significant economic consequences.

In the remainder of this paper, we present our econometric methods, including the simulation of the beta risk factor for four distinct exogenous shocks and its integration into a granular fragility measure of systemic risk. Based on these simulations, we construct a composite multidimensional measure of systemic risk. Subsequently, we apply our methodology to empirical data, using a sample of systemically important banks in Poland, followed by a discussion of the results and concluding remarks.

2. MD|SRISK: multi-dimensional systemic risk measure

Benoît et al. (2013, 2017) define systemic risk as a “hard-to-define-but-you-know-it-when-you-see-it concept” and distinguish two main categories of systemic risk measures. The first category, the source-specific approach, relies on internal data from financial firms (such as risk exposures or position taken) which are primarily available to supervisory units. This approach uses existing models to separately analyse specific sources of systemic risk, such as contagion, bank runs, or liquidity shocks. The second category, the global approach, employs widely available market data to estimate the optimal level of capital necessary for financial institution withstand systemic risk events.

Initial attempts to create a composite measure focused on the source specific approach and were mainly based on stress tests (Acharya et al., 2023). While existing measures, such as the ECB's Composite Indicator of Systemic Stress (CISS) and the STAMP€ stress testing tool, have made significant contributions to assessing systemic risk, they often operate in isolation, lacking a comprehensive view of the risk landscape (Dees et al., 2017).

Our approach is based on the systemic risk measure SRISK (Brownlees, Engle, 2017; Engle, 2018) and climate systemic risk concept CRISK (Jung et al., 2023) with adaptations for different types of exogenous shocks. This methodology is inspired by established statistical measures such as SES (Systemic Expected Shortfall) from Acharya et al. (2017), and is comparable to the ΔCoVaR measure introduced by Adrian & Brunnermeier (2016). The selection of this measure is based on its ability to capture sensitivity to external events and its prior application to other (non-market) external shocks, such as transition risk.

In this context, the term "system" specifically refers to the banking system, narrowly defined as a weighted sum of systemically important institutions (according to the EBA's definition of O-SII), as noted by Benoit et al. (2017). This methodology enables the analysis of the system's sensitivity to individual shocks, both at the level of each institution and as an aggregated measure for the system as a whole.

Then, the rate of return for the system at time t , denoted by r_t can be the weighted sum of the individual rates of return of the N institutions of N institutions:

$$r_t = \sum_{i=1}^N w_{i,t} \cdot r_{i,t} \quad (1)$$

where:

$w_{i,t}$ represents the weight of i -th institution in the system at time t (based on e.g. market capitalization or another metric, like SIFI or O-SII scores),

$r_{i,t}$ is the stock return rate of the i -th institution,

$i = 1, \dots, N$.

The systemic risk methodology uses publicly available market data and is based on the idea of capital shortfall CS_t defined on day t as in Brownlees & Engle (2017):

$$CS_t = \overbrace{k(D_t + V_t)}^{\text{capital reserves}} - \overbrace{\hat{V}_t}^{\text{current equity}} \quad (2)$$

where:

D_t is the book value of debt for the system,

V_t is the market value of system equity,

k is the prudential capital fraction.

Negative value of the capital shortfall means that the system has a capital surplus while positive value means lack sufficient amount of capital.

The SRISK measures the potential shortfall in capital that the system would likely need if a shock (systemic event) occurs within a specified time period h :

$$SRISK_t = \mathbb{E}(CS_{t+h} | \text{systemic event}) \quad (3)$$

Following ECB (2010) and Acharya et al., (2017), systemic event can be broadly understood as “financial instability spreading to the extent that the financial intermediation process is impaired and economic growth and welfare suffer materially”.

Formally, a systemic event is defined as the rate of return or rate of change $r_{t,t+h}^{risk\ factor} < \theta$, where θ is a shock threshold when the risk factor is in a negative trend (e.g. market shock), or $r_{t,t+h}^{risk\ factor} > \theta$ when the risk factor is in a positive trend (e.g. physical climate risk). The shock threshold can be defined as either a minimum value (for shocks in negative trends) or a maximum value (for positive trends), or as a given percentile of the historical rates of return or rates of change of the risk factor.

For simplicity, we define the system's variables as follows: $r_{t,t+h} \equiv r_t$.

An expected shortfall for shocks in negative trends is:

$$ES_t = \mathbb{E}(r_t | r_t^{risk\ factor} < \theta^{risk\ factor}) = \sum_{i=1}^N w_{i,t} \cdot \mathbb{E}(r_{i,t} | r_t^{risk\ factor} < \theta^{risk\ factor}) \quad (4)$$

where $\theta^{risk\ factor}$ is equal $Var_{t,t+h}^{risk\ factor,q} = -F_q^{-1}(r_{t-h,t}^{risk\ factor})$ with q being an arbitrarily chosen quantile of the distribution, and x being a return of risk factor proxy.

Following Acharya et al. (2012), the Marginal Expected Shortfall (MES) is then defined as a partial derivative:

$$MES_{i,t} = \frac{\partial ES_t}{\partial w_{i,t}} = \mathbb{E}(r_{i,t} | r_t^{risk\ factor} < \theta^{risk\ factor}) \quad (5)$$

On the other hand, an expected shortfall for the shock in positive trend is:

$$ES_t = \mathbb{E}(r_t | r_t^{risk\ factor} > \theta^{risk\ factor}) = \sum_{i=1}^N w_{i,t} \cdot \mathbb{E}(r_{i,t} | r_t^{risk\ factor} > \theta^{risk\ factor}) \quad (6)$$

And consequently:

$$MES_{i,t} = \frac{\partial ES_t}{\partial w_{i,t}} = \mathbb{E}(r_{i,t} | r_t^{risk\ factor} > \theta^{risk\ factor}) \quad (7)$$

Systemic risk, as described in formula (3), is the expected capital shortfall of a system in the event of a shock, and is defined using MES as follows:

$$SRISK_t = \overbrace{k(D_t + (1 - LRMES_t)V_t)}^{\text{required capital}} - \overbrace{(1 - LRMES_t)V_t}^{\text{current capital}} \quad (8)$$

where Long-Run Marginal Expected Shortfall (LRMES) is the conditional expectation of a system's multi-period return on equity over a specified time horizon, given that a systemic event occurs. As a random variable, LRMES must be estimated through appropriate statistical modelling techniques (described later in the paper for each case separately).

In the extreme case of stress scenario $LRMES_t \rightarrow 1$, meaning that market capitalization falls to 0, and $SRISK_t$ reflects the system shortage of capital over chosen horizon. According to this definition, the $SRISK$ represents the ex-ante capital buffer required to adequately withstand a financial crisis and is a function of system size, leverage and risk.

In practice, for managers, the primary concern is the shortage of necessary capital rather than any surplus. Therefore, $SRISK$ is formulated as:

$$SRISK_t = \max\{0; kD_t - (1 - k)(1 - LRMES_t)V_t\} \quad (9)$$

In fact, the above definition (9) is universal and can be written as:

$$XRISK_t = \max\{0; kD_t - (1 - k)(1 - LRMES_t^X)V_t\} \quad (10)$$

In this study, X represents a set of systemic shocks (risk factors) that includes four distinct types of shocks, each described by proxies. The impact of these shocks on the system is measured using the SRISK and climate CRISK metrics, with certain modifications to the latter (as shown in Table 1).

An exogenous factor, due to its mutual interdependence with the market factor, cannot be determined directly. For exogenous risks other than market risks, a method analogous to the Fama and French factor model was applied (Fama, French, 1993). In these cases, the mutual dependence between the analysed risk and market risk is considered.

Following the methodology introduced by Jung et al. (2023), the joint sensitivity of the system to compound risks S&XRISK, based on market stress and exogenous stress, is expressed as:

$$S\&XRISK_t = kD_t - (1 - k)(1 - LRMES_t^X)(1 - LRMES_t^{M|X})V_t \quad (11)$$

where $LRMES_t^X$ represents the conditional expectation of a system's multi-period return on equity over a specified time horizon, given that an exogenous event X occurs, $LRMES_t^{M|X}$ represents the conditional expectation when a market event X occurs which captures the interdependence between market shocks and external shocks. The isolated impact of an external factor is calculated under the assumption of no external shock ($LRMES_t^{M|X} = 0$) and is interpreted as the total capital injection required during stress (in isolation from the market impact), accounting for the existing capitalization of financial institutions.

Table 1.

Different types of potential shocks and their characteristics

Risk factor	Risk factor reference (proxy)	Trend of the risk factor	Measure
Market risk	Market stock index	Negative	SRISK
Transition climate risk	Stranded asset portfolio	Negative	TrCRISK
Physical climate risk	Term temperature anomaly	Positive	PhCRISK
Liquidity interbank risk	RMSE of curve-fitting model	Positive	LRISK

Source: own preparation.

Upon establishing the granular risk measures for individual exogenous shocks, the multidimensional aggregate measure of systemic risk is defined as the sum of non-negative granular risk values.

$$MD|SRISK_t = SRISK_t + TrCRISK_t + PhCRISK_t + LRISK_t \quad (12)$$

where:

$MD|SRISK_t$ is multidimensional systemic risk measure,

$SRISK_t$ is measure of system fragility for market stress scenario,

$TrCRISK_t$ measure of system fragility due to transition climate stress scenario,

$PhCRISK_t$ measure of system fragility due to physical climate stress scenario,

$LRISK_t$ measure of system fragility due to interbank liquidity stress scenario.

This methodology is sufficiently universal to integrate additional fragility measures for both external and internal stress scenarios.

2.1. Selection of references for exogenous shocks

2.1.1. Reference for the market risk

The choice of a broad stock market index as a market indicator is theoretically justified by its alignment with fundamental concepts from the Capital Asset Pricing Model (CAPM) developed by Sharpe (1964), which emphasize the importance of capturing systematic risk. Empirical studies have demonstrated that broad stock market indices, such as the S&P 500 or MSCI World, effectively capture market-wide movements and are highly correlated with the broader economy (Morgan, 1978; Bali et al., 2017). In research on local markets, the broad index of the local stock exchange is typically used.

2.1.2. Reference for the transition climate risk

To justify the choice of a proxy for transition climate risk, we aim to identify a market proxy that effectively captures this risk. One established approach, used by (Jung et al., 2023), involves constructing a portfolio based on stranded assets such as oil, fossil fuels, or coal, whose demand is expected to decline due to climate regulations such as the Paris Agreement. These industries are particularly vulnerable to transition risk, as their future profitability is expected to decrease with the shift toward carbon neutrality (van der Ploeg, Rezai, 2020; Bolton, Kacperczyk, 2021).

The stranded asset portfolio used by Jung et al. (2023), was originally developed by Litterman at WWF (Litterman, 2023), includes a 70% long position in the VanEck Coal Vectors ETF (KOL), a 30% long position in the Energy Select Sector ETF (XLE), and a short position in the S&P 500 ETF (SPY) via a total return swap (since KOL was delisted in 2021, it has been replaced by the average returns of its five largest holdings). The portfolio shows positive return when either XLE or KOL outperforms the market, and negative returns otherwise, reflecting heightened transition risk.

Alternative references (proxies) for transition climate risk can be constructed using other assets: a long position in ETFs or indices related to coal, oil and gas sectors (often referred as “brown industry” indices), and a short position in a broad market index (Reboredo, Ugolini, 2022; Semieniuk et al., 2022).

2.1.3. Reference for the physical climate risk

The term temperature anomaly, which represents deviations from long-term average temperature (typically over a 30-year period), is increasingly recognized as a reliable indicator for assessing physical climate risk. The theoretical basis for using temperature anomalies as a physical climate risk indicator stems from the assumption that unusual temperature patterns can disrupt economic activity, particularly in sectors directly dependent on climate conditions.

Since the empirical study by Cao and Wei (Cao, Wei, 2005), research by Faccia et al. (2021) Kahn et al. (2021) and Karydas & Xepapadeas (2022) has shown that weather deviations can impact economic activity, which in turn affects the financial performance of specific sectors. Other theoretical framework suggest that temperature anomalies are linked to fluctuations in stock prices (Gupta et al., 2023) and the significance of this impact has grown in recent years (Li et al., 2024). Additionally, studies by Faccia et al. (2021) Pagnottoni et al. (2022) Acharya et al. (2023) and Wu et al. (2023) highlight that temperature deviations can lead to increased risk and financial instability, particularly for banks exposed to climate-sensitive industries. While temperature anomalies play a central role in the choice of proxies for physical climate risk, other weather factors such as humidity, precipitation, rainfall, wind speed, and cloud cover are also important for identifying and managing the financial impacts.

2.1.4. Reference for the interbank liquidity risk

The significance of interbank liquidity for systemic risk was highlighted by Rochet and Tirole (1996), and the issue gained renewed attention following the 2007-2008 financial crisis, which spurred the development of new tools like stress tests (Cont et al., 2020). Moreover, Adrian et al. (2014) and Macchiati et al. (2022) emphasize the role of financial intermediaries in influencing stock returns, further linking liquidity to broader market outcomes and demonstrating the interbank market's impact on systemic risk.

Measuring interbank liquidity is particularly challenging due to mismatches errors and the difficulty of obtaining transaction-level data (Brunnermeier et al., 2014). Noise-based methods proposed by Hu et al. (2013) and Hattori (2021) offer alternative approaches for capturing liquidity dynamics. Research by Brunnermeier and Pedersen (2009) highlights that liquidity risk is closely linked to forecast accuracy, with increased forecasting errors leading to higher risk exposure. Similarly, studies by Adrian and Shin, (2010) and Adrian et al. (2017) demonstrate that inaccuracies in liquidity forecasting, reflected in high RMSE values, can negatively affect balance sheets and indicate heightened liquidity risk.

The root mean square error (RMSE) has become a tool for assessing interbank liquidity risk due to its ability to quantify the accuracy of liquidity forecasts. The theoretical basis for this application stems from the fact that RMSE measures forecasting errors, which directly reflects the stability and risk associated with liquidity management in financial institutions (Tsai, 2012).

2.2. SRISK: market systemic risk measure

For the calculation of SRISK, we define an external shock as the severe market decline, represented by the return of market stock index (as a proxy) $r_{m,t} < \theta^M$.

Following Brownlees & Engle (2017), and the V-Lab procedure utilizing the GARCH model, we estimate the Long-Run Marginal Expected Shortfall (LRMES) as follows:

$$LRMES_t^M = 1 - \exp(\beta_t^M \cdot \log(1 - \theta^M)) \quad (13)$$

where β_t^M represents the risk factor for market shocks.

To estimate beta parameter, we employ the GJR-GARCH for conditional volatility and the GARCH-DCC model to capture dynamic correlations:

$$\mathbf{r}'_t = \mathbf{H}_t^{1/2} \cdot \boldsymbol{\varepsilon}'_t \quad (14)$$

where $\mathbf{r}'_t = [r_{i,t}, r_{m,t}]$ is the transposed vector of returns at time t , and $\boldsymbol{\varepsilon}'_t = [\varepsilon_{i,t}, \varepsilon_{m,t}]$ is an i.i.d. vector with $\mathbb{E}(\boldsymbol{\varepsilon}_t) = 0$ and $\mathbb{E}(\boldsymbol{\varepsilon}_t \boldsymbol{\varepsilon}'_t)$ being a two-by-two identity matrix. The matrix $\mathbf{H}_t$ is defined as:

$$\mathbf{H}_t = \begin{bmatrix} \sigma_{i,t}^2 & \sigma_{i,t} \sigma_{m,t} \rho_{i,m,t} \\ \sigma_{i,t} \sigma_{m,t} \rho_{i,m,t} & \sigma_{m,t}^2 \end{bmatrix}, \quad (15)$$

where:

$\sigma_{m,t}$ and $\sigma_{i,t}$ are the conditional standard deviation at time t for the market and the financial institution i respectively,

$\rho_{m,i,t}$ is the time-varying conditional correlation coefficient.

In this time series framework, estimating the correlation structure introduces an additional layer of complexity, particularly because of the need to account for time-varying correlations. Modelling correlations as time-varying variables allows for a more dynamic and realistic representation of the risk environment. Failure to account for the time-varying nature of correlations has been shown to result in significant negative externalities, potentially underestimating systemic risk.

2.3. TrCRISK: transition climate systemic risk measure

For the estimation of transition climate systemic risk (TrCRISK), we define an external shock as a significant transition-related disruption, modelled by the return of stranded asset portfolio (as a proxy) $r_{tr,t} < \theta^{TrC}$.

The LRMES for climate transition risks is as follows:

$$LRMES_t^{TrC} = 1 - \exp(\beta_t^{TrC} \cdot \log(1 - \theta^{TrC})) \quad (16)$$

where β_t^{TrC} denotes the risk factor related to climate transition shocks.

To assess transition climate risk we follow the procedure delivered by Jung et al. (2023) and V-Lab, and we introduce a two-factor model analogous to the CAPM. This model takes into account the asset's exposure to both market risk and a stylized climate factor representing transition risk in this case. For the market factor, we follow standard practice by using the return of a broad equity index as a proxy. For the climate factor, we adopt a stranded asset portfolio as described above. This method reflects the market's perception of climate transition risk while isolating sector-specific risk from broader market performance.

To estimate beta coefficients, we use the dynamic conditional beta (DCB) model proposed by Engle, which uses a multivariate GARCH framework with dynamic conditional correlations (DCC-GARCH) to capture the time-varying nature of these sensitivities as in formula (14)

where $\mathbf{r}'_t = [r_{i,t}, r_{m,t}, r_{tr,t}]$ is the transposed vector of returns at time t , and $\boldsymbol{\varepsilon}'_t = [\varepsilon_{i,t}, \varepsilon_{m,t}, \varepsilon_{tr,t}]$ is an i.i.d. vector with $\mathbb{E}(\mathbf{v}_t) = 0$ and $\mathbb{E}(\mathbf{v}_t \mathbf{v}'_t)$ being a three-by-three identity matrix. The matrix $\mathbf{H}_t$ is defined as:

$$\mathbf{H}_t = \begin{bmatrix} \sigma_{i,t}^2 & \sigma_{i,t}\sigma_{m,t}\rho_{i,m,t} & \sigma_{i,t}\sigma_{tr,t}\rho_{i,tr,t} \\ \sigma_{i,t}\sigma_{m,t}\rho_{i,m,t} & \sigma_{m,t}^2 & \sigma_{m,t}\sigma_{tr,t}\rho_{m,tr,t} \\ \sigma_{i,t}\sigma_{tr,t}\rho_{i,tr,t} & \sigma_{m,t}\sigma_{tr,t}\rho_{m,tr,t} & \sigma_{tr,t}^2 \end{bmatrix}, \quad (17)$$

where:

$\sigma_{tr,t}$ is the conditional standard deviation of the stranded asset portfolio fragile for transition risk at time t ,

$\rho_{i,tr,t}$, $\rho_{m,tr,t}$ are the time-varying conditional correlation coefficients.

In this time series framework transitioning from a univariate to a multivariate process adds an additional layer of complexity, particularly due to the need to account for time-varying correlations. Modelling correlations as time-varying variables allows for a more dynamic and realistic representation of the risk environment. Neglecting the time-varying nature of correlations has been shown to result in significant negative externalities, potentially underestimating systemic risk.

The market beta β_t^M and transition climate beta β_t^{TrC} are estimated as follows:

$$\begin{bmatrix} \beta_t^M \\ \beta_t^{TrC} \end{bmatrix} = \begin{bmatrix} \sigma_{m,t}^2 & \sigma_{m,t}\sigma_{tr,t}\rho_{m,tr,t} \\ \sigma_{m,t}\sigma_{tr,t}\rho_{m,tr,t} & \sigma_{tr,t}^2 \end{bmatrix}^{-1} \begin{bmatrix} \sigma_{i,t}\sigma_{m,t}\rho_{i,m,t} \\ \sigma_{i,t}\sigma_{tr,t}\rho_{i,tr,t} \end{bmatrix} \quad (18)$$

2.4. PhCRISK: physical climate systemic risk measure

For estimating physical climate systemic risk (PhCRISK), an external shock is defined as a deviation from a baseline or average temperature which is modelled using the return of term temperature anomaly (as a proxy) that negatively affects the system. The impact is assessed by examining cases where the temperature anomaly exceeds a certain threshold, represented by the quantile $r_{ph,t} > \theta^{PhC}$, where $\theta^{PhC} \equiv VaR_t^{PhC,q}$, with q denotes the chosen quantile of the distribution.

The LRMES for climate physical risks is then given by:

$$LRMES_t^{PhC} = 1 - \exp\left(\beta_t^{PhC} \cdot \log\left(\frac{1}{1-\theta^{PhC}}\right)\right) \quad (19)$$

where β_t^{PhC} represents the risk factor associated with physical climate shocks.

The procedure for joint estimating beta coefficients is similar to that used for transition risk, with broad market index serving as the proxy for market risk.

2.5. LRISK: interbank liquidity risk measure

To estimate interbank liquidity systemic risk (LRISK), we define an external shock as a deviation from normal interbank liquidity conditions. This is modelled using the root mean square error (RMSE) of a curve-fitting Nelson-Siegel-Svensson (Nelson, Siegel, 1987; Svensson, 1994) model applied to interbank market data, where the negative impact on the system is assessed. Specifically, we examine cases where the RMSE of the liquidity curve-fitting model exceeds a certain threshold, represented by the quantile $r_{l,t} > \theta^L$, where $\theta^L \equiv VaR_t^{L,q}$, with q denotes the chosen quantile of the distribution.

The LRMES for interbank liquidity risk is given by:

$$LRMES_t^L = 1 - \exp\left(\beta_t^L \cdot \log\left(\frac{1}{1-\theta^L}\right)\right) \quad (20)$$

where β_t^L represents the risk factor associated with interbank liquidity shocks.

The procedure for estimating beta coefficients follows the same approach as for transition risk, with a broad market index serving as a proxy for market risk.

3. Empirical results of model implementation

The model was applied to the case of Poland, where it was assumed that the system consists of eight listed banks considered systemically important (O-SII): PKO BP, Pekao SA, Santander Bank Polska, ING Bank Śląski, mBank, Citi Handlowy, BNP Paribas Bank Polska, and Bank Millennium. Until 2015, the system was calculated as a weighted sum of banks' capitalization. Afterward, it was based on scores in line with the recommendations of the Polish Financial Supervision Authority (KNF) and the EBA/GL/2014/102 guidelines.

The empirical data sample spans the period from January 2005 to December 2023 and includes observations on the stock prices of the analysed banks, as well as proxies for shocks specific to the Polish market. The appendix provides descriptive statistics and indices. All data used in this article were sourced from LSEG (formerly Refinitiv Eikon).

Subsequently, the measures $SRISK_t$, $TrCRISK_t$, $PhCRISK_t$, $LRISK_t$ will be determined by considering external shocks (market shocks, climate transition risk, physical climate risk, and interbank market liquidity) tailored to the Polish market.

3.1. $SRISK_t$: market systemic risk measure

To measure a market shock threshold θ^M we use the broad Polish Warsaw Stock Exchange index (WIG) with $q = 1\%$, as recommended in the European Banking Authority's stress test guidance (EBA 2020). Consequently, $\theta^M = 44\%$. Figure 1 illustrates the ex-ante capital buffer (in total) that the system would likely require in the event of a shock (systemic event)

within the next six months (positive values). We omit the impact of negative SRISK values, as it is unlikely that capital surplus could be easily transferred between institutions, particularly during a crisis.

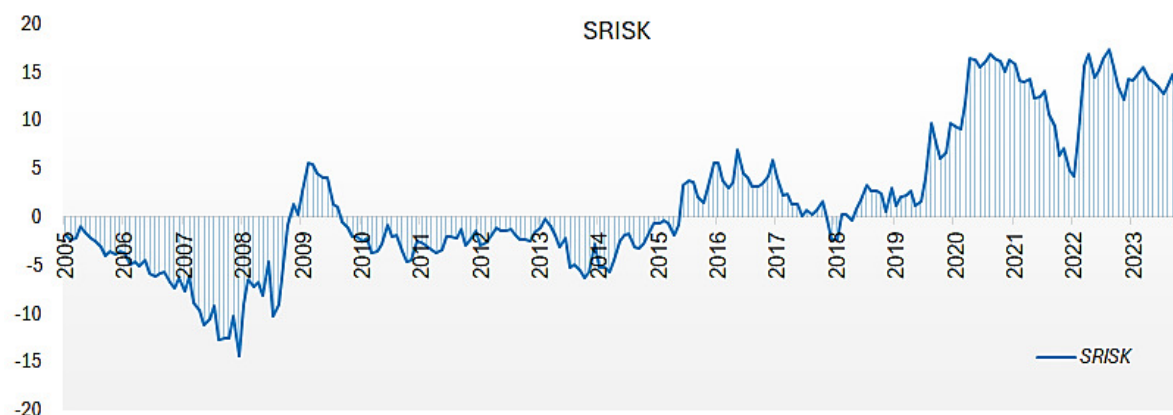


Figure 1. SRISK for Polish banking system (in bln EUR).

Source: own preparation.

3.2. $TrCRISK_t$: transition climate systemic risk measure

To capture the climate risk associated with the energy transition in the Polish market, a customised stranded assets portfolio was constructed following the approach of Jung et al. (2023). For the Polish market, the portfolio consists of a 70% long position in the WIG-mining sector index and a 30% long position in the WIG-fuels sector index, as well as a short position in a broad market index WIG. Both considered industry indices include major Polish energy and mining companies which face significant risks due to the transition to a low-emission economy. Since these indices were established on December 31, 2010 (mining) and December 31, 2005 (fuels), respectively, the earlier data was obtained using the WIG's Basic Index Algorithm Methodology (GPW, 2017).

By analysing the excess returns of this portfolio, we can estimate the climate transition risk these sectors face. A significant decline in excess returns suggests heightened transition risk, as market participants price in the decreasing profitability of these industries due to regulatory pressures and the shift towards carbon neutrality. To isolate the climate transition impact from market effects, the broad Warsaw Stock Exchange Index (WIG) is used as a market proxy.

We assume the following thresholds calculated for with $q = 1\%$: $\theta^{CTr} = 60\%$ for the climate transition risk event and $\theta^M = 44\%$ for the market event. Figure 2 illustrates the ex-ante capital buffer (in billion EUR) that the system would likely require in the event of a climate transition shock (isolated from the market shock) over the next six months.

The $TrCRISK$ value captures the growing sensitivity of the banking system to losses linked to stranded assets during the COVID-19 pandemic and following the outbreak of the war in Ukraine.

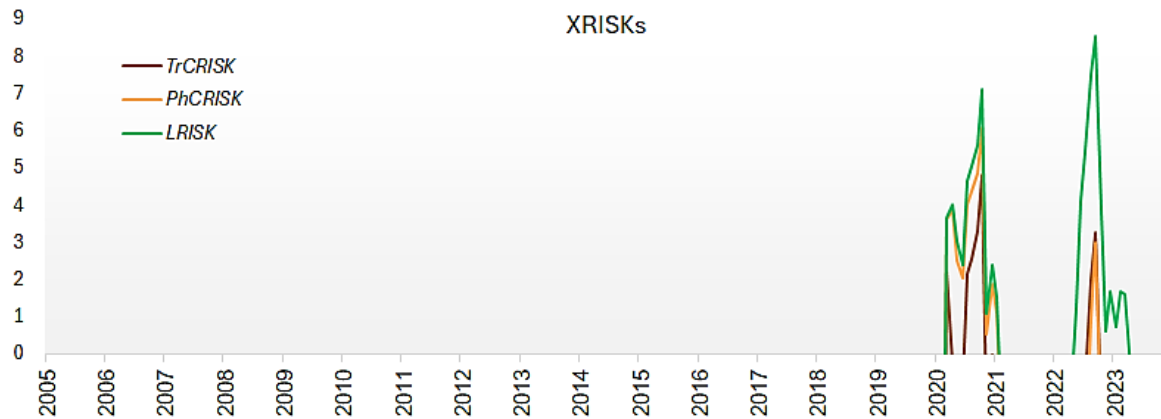


Figure 2. XRISKs measures for Polish banking system (in bln EUR).

Source: own preparation.

3.3. *PhCRISK_t*: physical climate systemic risk measure

To capture climate risk associated with physical factors in the Polish market, we used the temperature anomaly - defined as the deviation of the average annual temperature in Poland from the 30-year norm - as an external shock. Temperature data was sourced from the Institute of Meteorology and Water Management (IMiGW). We verified the significance of temperature variability's impact on systemic risk volatility using the methodology from Muhlack et al. (2022). The Long-Run MES was estimated based on the following shock levels: $\theta^{PhClimate} = 49\%$ and $\theta^{Market} = 44\%$.

During the period under review, temperature deviations from the long-term average had an increasing impact on the sensitivity of the banking system. Both the pandemic and the war in Ukraine affected the banking system's sensitivity to climate change. The war, along with the resulting energy crisis, particularly in Europe, focused market attention toward energy security and supply chain disruptions, temporarily sidelining concerns about rising temperatures (Figure 2).

3.4. *LRISK_t*: interbank liquidity systemic risk measure

For liquidity systemic risk, the interbank liquidity risk proxy was constructed using the RMSE from the Nelson-Siegel-Svensson curve-fitting approach (Dziwok, 2017). Higher RMSE values indicate larger forecasting errors and greater uncertainty in liquidity management, reflecting increased liquidity risk. Following the methodology of Jung et al., the Long-Run MES was estimated with shock levels set at: $\theta^{Liquidity} = 34\%$ and $\theta^{Market} = 44\%$, after verifying the impact of interbank liquidity variability on systemic risk volatility.

The impact of interbank liquidity risk became evident during the COVID-19 pandemic and the aggression against Ukraine. At that time, the system showed heightened sensitivity due to the increased demand for liquid funds across the entire banking sector (Figure 2).

3.5. $MD|RISK_t$: multi-dimensional systemic risk measure

Determining the system's sensitivity to four distinct types of shocks allows us to estimate the combined impact, representing the maximum potential sensitivity of the system to these shocks (Figure 3).

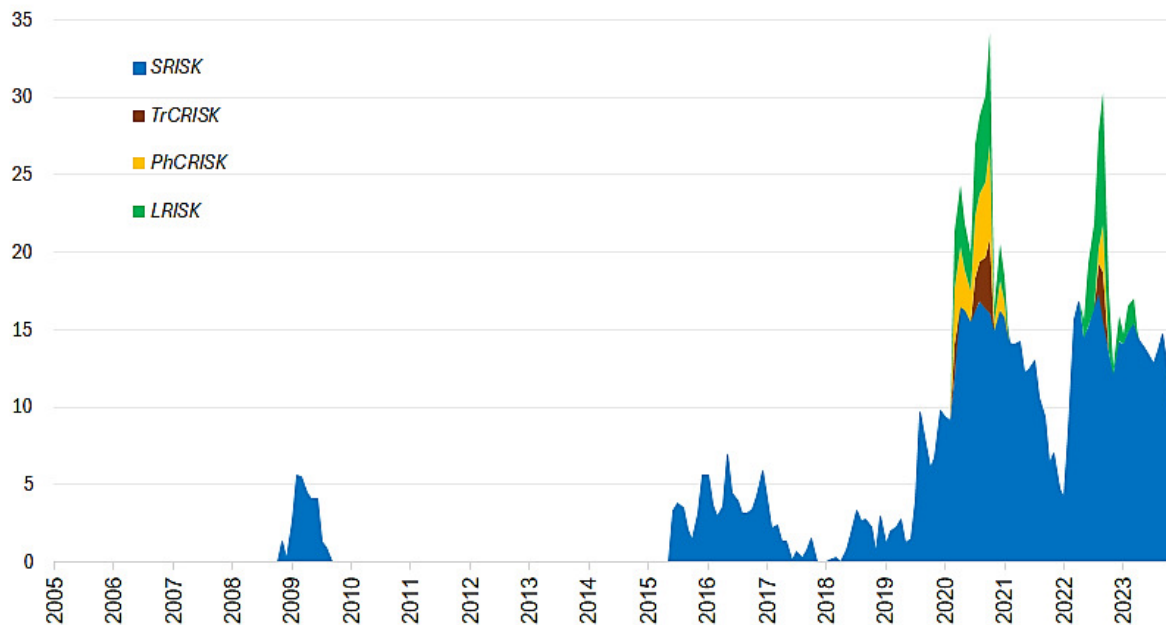


Figure 3. Multi-dimensional systemic risk measure for Polish banking system (in bln EUR).

Source: own preparation.

The study revealed that the system's response to shocks varies depending on the type of shock, although in most cases, there is a cumulative effect from multiple sources. A key factor affecting the system's vulnerability is the growing climate risk. While often overlooked in analyses of systemic risk in the Polish market, climate risk is becoming an important element that enhances system sensitivity.

4. Conclusions

The study allowed us to develop a measure to assess the sensitivity of the banking system to various exogenous shocks. With the modifications used, we were able to analyse the impact of individual exogenous shocks both in isolation and as a whole. Our methodology includes risk factors such as the stock market, climate risk and interbank liquidity.

The system's vulnerability to climate change - reflected through transition risk indicated by the stranded assets portfolio, and physical risk measured by temperature deviations from the multi-year average - proved to be a key factor. As a result, this study offers a more comprehensive analysis than previous studies conducted in Poland.

The empirical results confirmed an increase in systemic risk in Poland between 2008-2009 and 2011-2013, as well as a significant increase in risk associated with the COVID-19 pandemic and Russia's invasion of Ukraine. We also found that the impact of certain shocks varied significantly from others.

Our results confirm that systemic risk can be calculated by incorporating various exogenous shocks. This underscores the need to analyse systemic risk using sophisticated measures that highlight the nuances of the phenomenon. The results also demonstrate that the often-overlooked climate risk is a significant component of systemic risk. These results highlight the importance of analysing systemic risk in a multidimensional way, utilizing publicly available data.

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References

1. Acharya, V.V., Berner, R., Engle, R., Jung, H., Stroebel, J., Zeng, X., Zhao, Y. (2023). Climate Stress Testing. *Annual Review of Financial Economics*, 15(1), 291-326. <https://doi.org/10.1146/annurev-financial-110921-101555>
2. Acharya, V.V., Engle, R., Richardson, M. (2012). Capital Shortfall: A New Approach to Ranking and Regulating Systemic Risks. *American Economic Review*, 102(3), 59-64. <https://doi.org/10.1257/aer.102.3.59>
3. Acharya, V.V., Pedersen, L.H., Philippon, T., Richardson, M. (2017). Measuring Systemic Risk. *Review of Financial Studies*, 30(1), 2-47. <https://doi.org/10.1093/rfs/hhw088>
4. Adrian, T., Brunnermeier, M.K. (2016). CoVaR. *American Economic Review*, 106(7), 1705-1741. <https://doi.org/10.1257/aer.20120555>
5. Adrian, T., Etula, E., Muir, T. (2014). Financial Intermediaries and the Cross-Section of Asset Returns. *The Journal of Finance*, 69(6), 2557-2596. <https://doi.org/10.1111/jofi.12189>
6. Adrian, T., Fleming, M., Shachar, O., Vogt, E. (2017). Market Liquidity after the Financial Crisis. *Federal Reserve Bank of New York Staff Reports*, No. 796. https://www.newyorkfed.org/medialibrary/media/research/staff_reports/sr796.pdf
7. Adrian, T., Shin, H.S. (2010). Liquidity and leverage. *Journal of Financial Intermediation*,

- 19(3), 418-437. <https://doi.org/10.1016/j.jfi.2008.12.002>
8. Bali, T., Engle, R., Murray, S. (2017). Empirical Asset Pricing: The Cross Section of Stock Returns: An Overview. In: *Wiley StatsRef: Statistics Reference Online* (pp. 1-8). Wiley. <https://doi.org/10.1002/9781118445112.stat07954>
9. Basel Committee on Banking Supervision (2021). Climate-related financial risks – measurement methodologies. *BIS. April 2021*. <https://www.bis.org/bcbs/publ/d518.pdf>
10. Benoît, S., Colletaz, G., Hurlin, C., Pérignon, C. (2013). *A Theoretical and Empirical Comparison of Systemic Risk Measures*. <https://shs.hal.science/halshs-00746272v2>
11. Benoît, S., Colliard, J.-E., Hurlin, C., Pérignon, C. (2017). Where the Risks Lie: A Survey on Systemic Risk. *Review of Finance*, 21(1), 109-152. <https://doi.org/10.1093/rof/rfw026>
12. Bolton, P., Kacperczyk, M. (2021). Do investors care about carbon risk? *Journal of Financial Economics*, 142(2), 517-549. <https://doi.org/10.1016/j.jfineco.2021.05.008>
13. Brownlees, C., Engle, R.F. (2017). SRISK: A Conditional Capital Shortfall Measure of Systemic Risk. *Review of Financial Studies*, 30(1), 48-79. <https://doi.org/10.1093/rfs/hhw060>
14. Brunnermeier, M., Gorton, G., Krishnamurthy, A. (2014). Liquidity Mismatch Measurement. In: M. Brunnermeier, A. Krishnamurthy (Eds.), *Risk Topography: Systemic Risk and Macro Modeling*. National Bureau of Economic Research, University of Chicago Press. <https://www.nber.org/system/files/chapters/c12514/c12514.pdf>
15. Brunnermeier, M.K., Pedersen, L.H. (2009). Market Liquidity and Funding Liquidity. *Review of Financial Studies*, 22(6), 2201-2238. <https://doi.org/10.1093/rfs/hhn098>
16. Cao, M., Wei, J. (2005). Stock market returns: A note on temperature anomaly. *Journal of Banking & Finance*, 29(6), 1559-1573. <https://doi.org/10.1016/j.jbankfin.2004.06.028>
17. Carney, M. (2015, September 29). Breaking the tragedy of the horizon – climate change and financial stability. *Speech by Mr Mark Carney, Governor of the Bank of England and Chairman of the Financial Stability Board, at Lloyd's of London*. <https://www.bis.org/review/r151009a.pdf>
18. Chen, N., Jin, X., Xin, B. (2023). The impact of risk spillover network-based multidimensional systemic risks on the real economy. *Applied Economics*, 1-14. <https://doi.org/10.1080/00036846.2023.2277689>
19. Cont, R., Kotlicki, A., Valderrama, L. (2020). Liquidity at risk: Joint stress testing of solvency and liquidity. *Journal of Banking & Finance*, 118, 105871. <https://doi.org/10.1016/j.jbankfin.2020.105871>
20. Dees, S., Henry, J., Martin, R. (Eds.). (2017). *STAMP€: Stress-Test Analytics for Macprudential Purposes in the euro area*. European Central Bank.
21. Dziwok, E. (2017). Chosen Measures for Pricing of Liquidity. In: K. Jajuga, L.T. Orlowski, K. Staehr (Eds.), *Contemporary Trends and Challenges in Finance* (pp. 3-9). Springer International Publishing.
22. Engle, R. (2018). Systemic Risk 10 Years Later. *Annual Review of Financial Economics*,

- 10(1), 125-152. <https://doi.org/10.1146/annurev-financial-110217-023056>
23. ESRB (2021). *Climate-related risk and financial stability*, Iss. July. ECB.
 24. ESRB (2022). *The macroprudential challenge of climate change*. https://www.esrb.europa.eu/pub/pdf/reports/esrb.ecb.climate_report202207~622b791878.en.pdf
 25. European Central Bank (2010). *Financial Stability Review. December*, 147-153.
 26. Faccia, D., Parker, M., Stracca, L. (2021). Feeling the heat: extreme temperatures and price stability. *ECB Working Paper Series*, 2626. <https://www.ecb.europa.eu/pub/pdf/scpwps/ecb.wp2626~e86e2be2b4.en.pdf>
 27. Fama, E.F., French, K.R. (1993). Common risk factors in the returns on stocks and bonds. *Journal of Financial Economics*, 33(1), 3-56. [https://doi.org/10.1016/0304-405X\(93\)90023-5](https://doi.org/10.1016/0304-405X(93)90023-5)
 28. Foglia, M., Angelini, E. (2021). The triple (<scp>T3</scp>) dimension of systemic risk: Identifying systemically important banks. *International Journal of Finance & Economics*, 26(1), 7-26. <https://doi.org/10.1002/ijfe.2386>
 29. Freixas, X., Laeven, L., Peydró, J.-L. (2023). *Systemic Risk, Crises, and Macroprudential Regulation*. MIT Press.
 30. Giglio, S., Kelly, B., Stroebe, J. (2021). Climate Finance. *Annual Review of Financial Economics*, 13(1), 15-36. <https://doi.org/10.1146/annurev-financial-102620-103311>
 31. GPW (2017). *Warsaw Stock Exchange Indices. October*. https://www.gpw.pl/pub/GPW/files/indeksy/IndicesGPW_1017.pdf
 32. Gupta, R., Nel, J., Salisu, A.A., Ji, Q. (2023). Predictability of economic slowdowns in advanced countries over eight centuries: The role of climate risks. *Finance Research Letters*, 54, 103795. <https://doi.org/10.1016/j.frl.2023.103795>
 33. Hattori, T. (2021). Noise as a liquidity measure: Evidence from the JGB market. *Pacific-Basin Finance Journal*, 67, 101515. <https://doi.org/10.1016/j.pacfin.2021.101515>
 34. Hepburn, C., O'Callaghan, B., Stern, N., Stiglitz, J., Zenghelis, D. (2020). Will COVID-19 fiscal recovery packages accelerate or retard progress on climate change? *Oxford Review of Economic Policy*, 36(Supplement_1), S359-S381. <https://doi.org/10.1093/oxrep/graa015>
 35. Hochrainer-Stigler, S., Šakić Trogrlić, R., Reiter, K., Ward, P.J., de Ruiter, M.C., Duncan, M.J., Torresan, S., Ciurean, R., Mysiak, J., Stuparu, D., Gottardo, S. (2023). Toward a framework for systemic multi-hazard and multi-risk assessment and management. *IScience*, 26(5), 106736. <https://doi.org/10.1016/j.isci.2023.106736>
 36. Hu, G.X., Pan, J., Wang, J. (2013). Noise as Information for Illiquidity. *The Journal of Finance*, 68(6), 2341-2382. <https://doi.org/10.1111/jofi.12083>
 37. IMF (2009). Global Financial Stability Report (GFSR). Responding to the Financial Crisis and Measuring Systemic Risk. *World Economic and Financial Surveys*, April.
 38. Jourde, T., Moreau, Q. (2024). Systemic Climate Risk. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.4300469>

39. Jung, H., Engle, R., Berner, R. (2023). CRISK: Measuring the Climate Risk Exposure of the Financial System. *FRB of New York Staff Report, No. 977, March*.
40. Kahn, M.E., Mohaddes, K., Ng, R.N.C., Pesaran, M.H., Raissi, M., Yang, J.-C. (2021). Long-term macroeconomic effects of climate change: A cross-country analysis. *Energy Economics, 104*, 105624. <https://doi.org/10.1016/j.eneco.2021.105624>
41. Karydas, C., Xepapadeas, A. (2022). Climate change financial risks: Implications for asset pricing and interest rates. *Journal of Financial Stability, 63*, 101061. <https://doi.org/10.1016/j.jfs.2022.101061>
42. Klinke, A., Renn, O. (2002). A New Approach to Risk Evaluation and Management: Risk-Based, Precaution-Based, and Discourse-Based Strategies 1. *Risk Analysis, 22*(6), 1071-1094. <https://doi.org/10.1111/1539-6924.00274>
43. Li, C., Liu, Y., Pan, L. (2024). A study of impact of climate change on the U.S. stock market as exemplified by the NASDAQ 100 index constituents. *Scientific Reports, 14*(1), 15468. <https://doi.org/10.1038/s41598-024-66109-7>
44. Li, H.-M., Wang, X.-C., Zhao, X.-F., Qi, Y. (2021). Understanding systemic risk induced by climate change. *Advances in Climate Change Research, 12*(3), 384-394. <https://doi.org/10.1016/j.accre.2021.05.006>
45. Litterman, B. (2023). *Selling Stranded Assets: Profit, Protection, and Prosperity*. Fact Sheet. Intentional Endowments Network (IEN). https://www.intentionalendowments.org/selling_stranded_assets_profit_protection_and_prosperity
46. Macchiati, V., Brandi, G., Di Matteo, T., Paolotti, D., Caldarelli, G., Cimini, G. (2022). Systemic liquidity contagion in the European interbank market. *Journal of Economic Interaction and Coordination, 17*(2), 443-474. <https://doi.org/10.1007/s11403-021-00338-1>
47. Montagna, M., Torri, G., Covi, G. (2020). On the Origin of Systemic Risk. *ECB Working Paper Series, No. 2502, December*. <https://doi.org/10.2139/ssrn.3749361>
48. Morgan, I.G. (1978). Market proxies and the conditional prediction of returns. *Journal of Financial Economics, 6*(4), 385-398. [https://doi.org/10.1016/0304-405X\(78\)90011-9](https://doi.org/10.1016/0304-405X(78)90011-9)
49. Nelson, C., Siegel, A.F. (1987). Parsimonious Modeling of Yield Curves. *The Journal of Business, 60*(4), 473-489. <https://econpapers.repec.org/RePEc:ucp:jnlbus:v:60:y:1987:i:4:p:473-89>
50. Nguyen, Q., Diaz-Rainey, I., Kuruppuarachchi, D. (2023). In search of climate distress risk. *International Review of Financial Analysis, 85*, 102444. <https://doi.org/10.1016/j.irfa.2022.102444>
51. Pagnottoni, P., Spelta, A., Flori, A., Pammolli, F. (2022). Climate change and financial stability: Natural disaster impacts on global stock markets. *Physica A: Statistical Mechanics and Its Applications, 599*, 127514. <https://doi.org/10.1016/j.physa.2022.127514>
52. Reboredo, J.C., Ugolini, A. (2022). Climate transition risk, profitability and stock prices. *International Review of Financial Analysis, 83*, 102271. <https://doi.org/10.1016/j.irfa.2022.102271>

53. Renn, O., Klinke, A., Schweizer, P.-J. (2018). Risk Governance: Application to Urban Challenges. *International Journal of Disaster Risk Science*, 9(4), 434-444. <https://doi.org/10.1007/s13753-018-0196-3>
54. Rochet, J.-C., Tirole, J. (1996). Interbank Lending and Systemic Risk. *Journal of Money, Credit and Banking*, 28(4), 733. <https://doi.org/10.2307/2077918>
55. Semieniuk, G., Holden, P.B., Mercure, J.-F., Salas, P., Pollitt, H., Jobson, K., Vercoulen, P., Chewpreecha, U., Edwards, N.R., Viñuales, J.E. (2022). Stranded fossil-fuel assets translate to major losses for investors in advanced economies. *Nature Climate Change*, 12(6), 532-538. <https://doi.org/10.1038/s41558-022-01356-y>
56. Sharpe, W.F. (1964). Capital Asset Prices: A Theory of Market Equilibrium Under Conditions of Risk. *The Journal of Finance*, 19(3), 425-442. <https://doi.org/10.1111/j.1540-6261.1964.tb02865.x>
57. Smaga, P. (2014). The Concept of Systemic Risk. *Systemic Risk Centre Special Paper, Vol. 5*. <https://eprints.lse.ac.uk/61214/1/sp-5.pdf>
58. Svensson, L.E.O. (1994). Estimating and Interpreting Forward Interest Rates: Sweden 1992-1994. *IMF Working Papers*, 94(114), 1. <https://doi.org/10.5089/9781451853759.001>
59. Tsai, S.-C. (2012). Liquidity and Yield Curve Estimation. *Emerging Markets Finance and Trade*, 48(5), 4-24. <https://doi.org/10.2753/REE1540-496X480501>
60. Undheim, T.A. (2024). An interdisciplinary review of systemic risk factors leading up to existential risks. *Progress in Disaster Science*, 22, 100326. <https://doi.org/10.1016/j.pdisas.2024.100326>
61. van der Ploeg, F., Rezai, A. (2020). Stranded Assets in the Transition to a Carbon-Free Economy. *Annual Review of Resource Economics*, 12(1), 281-298. <https://doi.org/10.1146/annurev-resource-110519-040938>
62. Wu, X., Bai, X., Qi, H., Lu, L., Yang, M., Taghizadeh-Hesary, F. (2023). The impact of climate change on banking systemic risk. *Economic Analysis and Policy*, 78, 419-437. <https://doi.org/10.1016/j.eap.2023.03.012>

EFFICIENCY, PROFITABILITY AND CREDIT ACTION OF STATE AND PRIVATE BANKS DURING COVID-19 AND THE WAR IN UKRAINE

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Purpose: The objective of this study is to ascertain whether, during the global pandemic caused by the SARS-CoV-2 virus and the outbreak of war in Ukraine – commercial banks operating in the Polish market demonstrated differentiation in terms of efficiency, profitability, and the volume and quality of lending resulting from the state or non-state nature of institutions with a decisive role in ownership supervision.

Design/methodology/approach: The study undertook a review of the existing literature on the impact of banks under state control on the performance of the country's financial sector and economy. It then proceeded to undertake a comparison of the size and dynamics of change in efficiency, profitability and asset quality indicators achieved by 19 commercial banks.

Results: A comparison of the value and dynamics of change in the economic indicators of banks, taking into account the nature of the institutions exercising ownership control, revealed that the hypothesis that there were no differences between the distinguished groups could be rejected. State-dependent banks exhibited higher volatility of efficiency indicators and lower resilience to the impact of the pandemic. Additionally, they exhibited higher profitability outside the year of the pandemic's outbreak, a higher commitment of capital to lending, and a poorer quality of the loan portfolio.

Research limitations/implications: The findings of the study substantiate the differentiation between state-owned and private banks. State-owned banks are more inclined to take risks and maintain lending during periods of economic turbulence and heightened market volatility. The limited number of commercial banks operating as joint-stock companies in Poland during the 2019-2023 period constrained the scope for employing more advanced statistical analysis tools. To corroborate the findings, it would be prudent to undertake a further study encompassing a more diverse range of banks, for instance, those from Central and Eastern European countries.

Originality/value: The paper presents, to the best of the author's knowledge, the results of the first study to compare the financial performance of private and state-owned banks in Poland during two significant global crises. It could be an important contribution to the ongoing debate surrounding the potential sale of some banking assets by the Treasury.

Keywords: bank, state ownership, crisis, risk, financial result.

Category of work: research article.

1. Introduction

One of the consequences of the global financial crisis of 2007-2009 was a shift in the perception of foreign capital within the Polish banking sector. Prior to the onset of the crisis, it was regarded as a favourable phenomenon by both consumers and economists. The reason for this shift in perception was the dynamic development of the banking sector in Poland following the influx of capital, the notable enhancement in the quality of financial services, and the infusion of both capital and technology into the sector (Godula, 2001). However, with the advent of the crisis, concerns emerged regarding the potential outflow of foreign capital from Poland to its home countries. This could result in a transfer of the sector's liquidity issues, akin to those observed during the global financial crisis in other countries, a reduction in the level of enterprise financing, and a subsequent deceleration in the country's economic growth (Kawalec, Gozdek, 2012).

The global financial crisis did not result in a recession in Poland, which was an exceptional phenomenon on a European scale. This afforded politicians the opportunity to portray Poland as a green island of economic growth. The favourable portrayal of the Polish economy in comparison to the less optimistic outlook for other EU countries led politicians, publicists and some economists to advocate a reduction in the proportion of foreign capital in the banking sector and an increase in the share of Polish capital (Mleczko, 2016; Pyka, Pyka, 2017; Pyka, Nocoń, 2018). Specific solutions in this regard were presented, among others, by Stefan Kawalec, who stated, among other things, that: "an acceptable alternative to foreign control of banks may be dispersed private ownership, while it is not a desirable alternative to increase direct or indirect state ownership control" (Kawalec, Gozdek, 2012, p. 6). However, this recommendation has not been fully taken into account by politicians, who have admittedly increased the share of Polish capital in the banking sector, but precisely by having the Treasury take control of banks sold by their existing foreign owners.

The process of increasing the share of state capital in the banking sector commenced during the tenure of the PO-PSL coalition government in 2014, with the acquisition of Nordea Bank Polska's assets by PKO Bank Polski, which is under the control of the Ministry of Finance through a 30% stake. Another transaction occurred during the tenure of the Prawo i Sprawiedliwość (PiS) government in 2015, when PZU (34% of shares owned by the Treasury Ministry) repurchased shares in Alior Bank from the Carlo Tassara Group. Two years later, in 2017, PZU repurchased a 20% stake, while the Polish Development Fund (99.87% of shares owned by the Prime Minister's Office) repurchased a 12.8% stake in Bank Pekao from Uni Credit (Gostomski, Lepczynski, 2019; Orbis, 2024). A further expansion of the state's holding in the banking sector occurred in late 2020 and early 2021, when the Bank Guarantee Fund announced the commencement of a compulsory restructuring of Idea Bank and its subsequent acquisition by Bank Pekao (Jastrzębski, Machalski, 2022). The final bank to be nationalised

was Getin Noble Bank, which underwent a resolution process overseen by the Bank Guarantee Fund and was subsequently transformed into VeloBank and sold to a foreign investor in 2024 (Zaleska, 2023).

The repolonization of the banking sector, which constituted a form of nationalization, resulted in a transformation of the sector's ownership structure. In 2008, the largest share in the sector was held by foreign investors, who controlled 72.3% of assets (Mierzwa, Jankiewicz, 2017). Subsequently, state-controlled capital assumed an increasingly pivotal role. In December 2019, the Treasury held 40% assets (Informacja na temat sytuacji..., 2021), in December 2020 44.2% (Informacja na temat sytuacji..., 2021), in December 2021 46.2% and in December 2022, it held 47.5% (Informacja na temat sytuacji..., 2023).

The state's significant involvement in the banking sector has prompted concerns among numerous economists, who have highlighted potential inefficiencies in the management of the sector. The group of experts includes Jan Krzysztof Bielecki, former chairman of Pekao Bank; Stefan Kawalec, who was one of the proponents of repolonization of the banking sector; Wojciech Kwaśniak, former inspector general of banking supervision; Sławomir Lachowski, former chairman of BRE Bank; and Andrzej Reich, former member of the Committee of European Banking Supervisors (Goniszewski, 2023). The aforementioned economists highlight several potential issues with the current state of banking supervision in Poland. Firstly, they argue that the supervision of banks may be ineffective when both the bank and the supervisor are subordinate to the same state-owned institution. Secondly, they suggest that managers may be susceptible to political influence if they are recruited along party lines rather than on competence. Thirdly, they raise concerns about the potential risk of financing investments that are not economically justified but politically justified. Finally, they point out that the competition between banks controlled by the same owner may be weakened.

The 2020s commenced with the advent of two crises that presented significant challenges to the financial sector. The initial challenge was the emergence of the SARS-CoV-2 virus, which became known as the novel coronavirus disease (Covid-19) in early 2020. The second event was the outbreak of war in Ukraine in early 2022. This study will undertake a comparative analysis of the efficiency, profitability and commitment to lending of Polish banks with state and private capital ownership during the period encompassing both events. The principal aim of this study is to ascertain whether the hypothesis that state-controlled banks played a stabilising role in the banking sector and the Polish economy during the two crisis periods is indeed valid. Second-order objectives to achieve the primary objective are as follows:

1. To ascertain whether banks under state control achieved efficiency and profitability that differed from private banks, thus affecting the stability of the entire banking sector in a positive or negative manner.
2. To determine whether banks under state control conducted lending that differed in size and volatility from private banks, thus affecting the stability of the overall economy in a positive or negative manner.

In order to achieve the stated goals, three hypotheses will be verified. These are as follows:

H1: Banks under state control did not differ in efficiency from private banks in 2019-23.

H2: Banks under state control did not differ in profitability from private banks in 2019-23.

H3: Banks under state control did not differ in their lending activity from private banks in 2019-23.

The following section will commence with a review of the extant literature on the impact of state-controlled banks on the performance of the banking sector and the national economy. Subsequently, the findings of previous research on the impact of the Coronavirus Disease 2019 (Covid-19) pandemic and the war in Ukraine on the performance of the banking sector will be presented, with a particular focus on the Polish banking sector. The following section will present a comparison of the value and dynamics of change in efficiency, profitability and lending ratios of Polish state-dependent banks to Polish banks dependent on private shareholders. The study will conclude with a presentation of the conclusions and a verification of the hypotheses posed in the introduction.

2. Literature review

2.1. An examination of the literature concerning the evaluation of state-controlled banks

The studies carried out in the 21st century on the efficiency of banks under state control and their impact on the country's economy can be divided into two main groups. The first group of studies presents a clear argument that state banks are less efficient and have a detrimental impact on economic development. In contrast, the second group of studies offers a more complex picture, suggesting that the financial performance and the impact of state banks on the economy are influenced by a range of factors, including the stage of the business cycle, the type of crisis affecting the country, the efficiency and level of economic development of the state, and the strength of political interference.

James R. Barth, Gerard Caprio Jr. and Ross Levine showed in a 2001 study (Barth, Caprio Jr., Levine, 2001) that state ownership of banks is associated with low efficiency for these institutions and lower levels of financial development for the country. Low efficiency for Argentine banks under state control was also shown in a study by Allen N. Berger and others in 2005 (Berger et al., 2005).

In their 2002 study, Rafael La Porta, Florencio Lopez-de-Silanes and Andrei Shleifer identified a correlation between government ownership of banks and a number of economic and political factors. They found that countries with low per capita income, underdeveloped financial systems, interventionist and inefficient governments, and weak protection of property rights tend to have higher levels of government ownership of banks. The study found that higher

government ownership of banks in 1970 is associated with slower subsequent financial development and lower per capita income and productivity growth (La Porta, Lopez-de-Silanes, Shleifer, 2002).

In 2005, Serdar Dinc posited that government-owned banks increase lending during election years at a higher rate than private banks. This observation points to the possibility that the decisions of these institutions' managers are influenced by factors beyond purely economic considerations. Dinc's calculations indicate that the increase in lending amounted to approximately 11% of the government-owned bank's total loan portfolio, which represented approximately 0.5% of the country's GDP (Dinc, 2005). The consequences of such action were elucidated in a study conducted in 2007. Alejandro Micco, Ugo Panizza, and Monica Yañez. The study revealed that state-controlled banks in developing countries tend to exhibit lower profitability and higher costs than their private counterparts, with the discrepancy becoming more pronounced during election years (Micco, Panizza, Yañez, 2007). A 2013 study also demonstrated the realisation of political goals by state-controlled banks. The following authors contributed to this field of study: Giuliano Iannotta, Giacomo Nocera and Andrea Sironi. It was observed that government-dependent banks exhibited a lower insolvency risk but a higher operational risk than private banks, with both indicators demonstrating an increase during election years (Iannotta, Nocera, Sironi, 2013). The subsequent year saw Daniel Carvalho present evidence that politicians in Brazil utilise the lending of government-dependent banks to influence job growth, directing it towards politically favourable regions at the expense of less politically attractive ones (Carvalho, 2014).

In a 2007 study, Thorsten Beck, Asli Demirguc-Kunt and Maria Soledad Martinez Peria found that state ownership of banks can have a negative impact on access to bank branches and ATMs. However, this does not result in a reduction in access to loans and deposits (Beck, Demirguc-Kunt, Martinez Peria, 2007).

In their study of Asian banks in the aftermath of the 2010 financial crisis, Marcia Millon Cornett, Lin Guo, Shahriar Khaksari and Hassan Tehranian observed that "...state-owned banks operated less profitably, held less core capital, and had greater credit risk than privately-owned banks prior to 2001, and the performance differences are more significant in those countries with greater government involvement and political corruption in the banking system" (Cornett et al., 2010). This finding is consistent with the results observed for Indian banks by Shawn Cole in 2009, who identified a higher proportion of non-performing loans in banks under state control (Cole, 2009). Furthermore, Alessandro Carretta and colleagues (2012) also observed this phenomenon in Italian banks. The study revealed that the proportion of politicians on a bank's board of directors had a substantial negative effect on net interest income, loan portfolio quality and capitalisation levels. However, it also demonstrated a positive impact on bank performance (Carretta et al., 2012). In 2013, Chunxia Jiang, Shujie Yao and Genfu Feng provided an illustrative example of how the politicisation of banks can have a detrimental impact on their performance. During the 2008-2009 period, the Chinese government, through

the banks under its control, encouraged local governments to make investments without conducting adequate credit risk assessments. This resulted in the generation of \$4.8 trillion in lending, which now represents a significant risk to the stability of China's banking sector. Additionally, the authors' findings highlight the inefficiency of state-dependent banks, suggesting the need for further privatisation of Chinese banks (Jiang, Yao, Feng, 2013).

In the year 2021 in an analysis prepared for the Forum Obywatelskiego Rozwoju on banking and investment threats to the development of the Polish economy, Kawalec and Katarzyna Blazuk identified the state as the most vulnerable type of bank owner. They put forth the proposition that capital may be allocated in an economically inefficient but politically advantageous manner through lending, and that limitations may be placed on the supervision of state-dependent institutions. As evidence, they cited a 2008 directive from the Financial Supervisory Commission (pol. Komisja Nadzoru Finansowego – KNF) recommending that no dividends be paid. Foreign-controlled banks whose parent companies suffered from a lack of capital during the global financial crisis complied with the directive, whereas state-controlled PKO BP paid a dividend to its shareholder, the state budget (Kawalec, Blazuk, 2021).

In 2022, Sahil Chopra published an article in which he discussed the shortcomings of banks under state control in India. Following an analysis of data from 2004 to 2020, he concluded that they were demonstrating a less favourable financial performance than that observed in private banks. He identified the following factors as contributing to this outcome: "The considerable number of loans approved in priority sectors, unfair practices due to interest groups, corruption, and staff inefficiency in public sectors" (Chopra, 2022). Similarly, Peter Njagi Kirimi reached comparable conclusions in 2024 after a comparative analysis of the efficiency of private and state-owned banks in Kenya. His study revealed that the country's state-owned banks exhibited suboptimal efficiency, and he identified deficiencies in corporate governance and government interference in bank management as the underlying causes (Kirimi, 2024).

Notwithstanding the unfavourable appraisals of the operations of state-owned banking institutions previously referenced, just prior to the global financial crisis, the stabilising function of banks during periods of economic turbulence and their capacity to mitigate business cycle volatility commenced to be acknowledged. As early as 2006, Alejandro Micco and Ugo Panizza presented evidence indicating that state-owned banks can contribute to the equalisation of the credit cycle and are less susceptible to macroeconomic shocks than private banks. Concurrently, two significant inquiries remained unanswered: whether augmented lending by state-controlled banks is allocated optimally to the economy and whether this lending displaces credit by private banks (Micco, Panizza, 2006). In the following year, Levy Yeyati, Alejandro Micco and Ugo Panizza reached a similar conclusion regarding the countercyclical action of state-owned banks. The authors highlighted that while their study corroborated the assertion that public banks do not allocate credit optimally, the evidence indicating that state ownership impedes financial development and growth was already less certain than previously thought. Additionally, evidence emerged suggesting that public banks may play a role in reducing credit procyclicality

(Yeyati, Micco, Panizza, 2007). These findings were corroborated in 2013 by Michael Brei and Alfredo Schclarek in a sample of 764 major banks based in 50 countries from 1994 to 2009 (Brei, Schclarek, 2013).

In 2012, Chung-Hua Shen and Chih-Yung Lin employed a two-group classification system for state-owned banks. Utilising banking data from 65 countries between the years 2003 and 2007, the researchers divided banks under state control into two categories: those that experience political interference and those that do not. The criterion for the division was the replacement of the bank's board of directors one year after the elections that took place in the country. If such an exchange took place, the bank was classified as experiencing political interference. If not, it was classified as a bank not experiencing political interference. The result of the study was a clear finding that state banks experiencing political interference perform worse financially than state banks not experiencing political interference (Shen, Lin, 2012).

The impact of state-dependent banks on the smoothing of the business cycle may vary across different geographical regions. Robert Cull and María Soledad Martínez Pería demonstrated that, during the global financial crisis, state-dependent banks in Latin America exhibited countercyclical lending behaviours, whereas the same institutions in Eastern Europe did not. Furthermore, prior to the crisis, the latter acted pro-cyclically, increasing lending at the same time as private banks, whereas those in Latin America did not (Cull, Martínez Pería, 2013).

A further study, published in 2015, provides confirmation of the countercyclical capabilities of state-dependent banks. In a study conducted by Atıcı Can Bertay, Asli Demirgüç-Kunt and Harry Huizinga, the financial performance of 1633 banks from 111 countries was analysed over the period 1999-2010. The findings indicated that state-owned banks are better placed to allocate credit in a less pro-cyclical manner, thereby playing a stabilising role during crises. However, the authors cautioned that, given the poor history of credit allocation by state banks, the use of such institutions as a short-term countercyclical tool is not advisable. Furthermore, the characteristics of the state apparatus itself represent an additional limitation, as evidenced by their research. The pro-cyclical behaviour of state-controlled banks is less pronounced in well-governed countries, characterised by the provision of effective public services, a high degree of independence from political pressures and a government that is perceived as being committed to the effectiveness of its policies. In high-income countries, state-controlled banks may even engage in countercyclical lending (Bertay, Demirgüç-Kunt, Huizinga, 2015). The same conclusions were reached in 2016 Yan-Shing Chen, Yehning Chen, Chih-Yung Lin and Zenu Sharma. A sample of banks from 58 countries was used to examine the provision of credit by state-dependent banks during the global financial crisis. The researchers discovered that these banks engaged in more extensive lending during this period. In countries with minimal corruption, this resulted in enhanced performance for these banks and accelerated GDP growth and reduced unemployment. Conversely, in countries with elevated corruption,

augmented lending led to a decline in the performance of state banks and had no impact on GDP and employment (Chen et al., 2016).

In the year 2018, Robert Cull, Maria Soledad Martinez Peria and Jeanne Verrier conducted a further examination of the impact of different forms of ownership on the performance of banks and their contribution to the national economy. The research concentrated on three key areas: the efficiency of banks and the level of competition between them, the stability of the financial sector and the availability of credit to the wider economy. The findings revealed that state ownership in the banking sector can help to stabilise the supply of credit during a crisis. However, it has a negative impact on competition and banking efficiency, and can affect the availability of banking services in different ways (Cull, Martinez Peria, Verrier, 2018).

The shift in economists' perceptions of state-owned banks is evidenced by a 2020 report by the European Bank for Reconstruction and Development (EBRD) that delineates the role and efficacy of the state in various countries and sectors. In the section on state-dependent banks, EBRD analysts conclude that state-owned banks, by accepting higher levels of risk, can mitigate the negative consequences of crises for households and small and medium-sized businesses. However, the cost of such policies is lower levels of business innovation and productivity due to political interference in state banks' lending decisions, especially during election periods (State banks on the rise..., 2020).

A study was conducted in 2020 to confirm the countercyclical nature of lending by banks under the control of the State Treasury, which forms part of the Polish banking sector. In their study, Marcin Borsuk and Oskar Kowalewski demonstrate that during the 2008-2009 global financial crisis, state-owned banks in Poland extended loans at a rate 7.6 percentage points higher than that observed in other commercial banks (Borsuk, Kowalewski, 2020).

In recent years, two studies of banks under state control have been conducted by Ugo Panizza. In the first study, conducted in 2023, no negative correlation was found between state ownership of banks and economic growth. Additionally, it was observed that instances of banking crises result in an increase in state control of banks. However, no evidence was found to suggest that this increase in state control causes further crises. Additionally, no distinction was observed between the profitability of private and public banks situated in emerging and developing economies. Instead, the findings confirmed that banks under state control exhibit less procyclical behaviour in these countries (Panizza, 2023). However, in a subsequent study conducted in 2024, Panizza corroborates earlier findings by other researchers that these banks are less profitable and have a higher share of non-performing loans. Furthermore, he reiterates that they serve to stabilise lending in the event of domestic shocks. He posits that the lower profitability is a consequence of a riskier loan portfolio and higher non-interest expenses, particularly personal expenses (Panizza, 2024).

In conclusion, the results of studies conducted in the 21st century on the impact of state ownership on the efficiency of banks and its impact on economic development indicate that this form of ownership is associated with considerable risks. These are primarily manifested in the

form of inadequate corporate governance and an inefficient distribution of capital within the economy. This results in the assumption of a higher level of risk in lending, less well-prepared personnel to manage the bank, which in turn undermines economic development and innovation, and a worse profitability of state-owned banks than private banks. This ultimately undermines the stability of the banking sector as a whole. Nevertheless, there are circumstances in which the majority of these risks can be mitigated. The first and foremost condition for the success of state-owned banks is the absence of political interference in their management. This condition is most often met in countries with developed economies. State-owned banks can also play a positive role in dampening business cycle fluctuations by lending less than private banks in good times and more in crisis periods. This impact has been noted mainly in the case of negative external impulses, and during these periods state banks can play a stabilising role in the banking sector.

2.2. The Effect of the Coronavirus Pandemic and the War in Ukraine on the Polish Financial Sector

On 11 March 2020, the World Health Organization (WHO) declared a pandemic due to the novel coronavirus, SARS-CoV-2, which causes the disease known as coronavirus disease 2019 (Covid-19). On 20 March, Poland was placed in an epidemic state, although as of 12 March, educational institutions had already transitioned to remote learning and cultural activities had been suspended. Further restrictions were subsequently introduced, including a directive limiting all non-essential travel. This resulted in the cessation of numerous services and significant economic disruption, ultimately leading to an economic recession.

The initial shock to the banking system was a substantial decline in economic activity. Furthermore, the actions of the National Bank of Poland, which were designed to mitigate the economic impact of the pandemic, imposed additional burdens on the banking sector. Despite the persistence of inflationary pressures and market expectations of an imminent interest rate hike, the Monetary Policy Council opted to reduce interest rates. Three reductions, on 18 March, 9 April and 29 May, resulted in interest rates in Poland reaching their lowest level to date. The reference rate was set at 0.10%, the Lombard rate at 0.50%, and the deposit rate at 0. Such low interest rates prompted banks to modify their asset and liability management models, leading to a decline in interest margins and interest earnings. Additionally, the aforementioned circumstances prompted an exodus of capital from deposit accounts, as customers sought alternative avenues for the preservation of their savings, preferring the accessibility of funds in current accounts. Concurrently, there was a notable reduction in the volume of loans granted, which was also attributable to a decline in demand. From a business perspective, this was due to a cessation of planned investments. From a consumer standpoint, it was due to a cessation of planned spending and an increase in savings in anticipation of potential future risks. In order to cope with the resulting excess liquidity, banks increased their investments in fixed-rate securities issued by the Polish Development Fund. Consequently, during the period of low

interest rates, they became susceptible to subsequent interest rate increases, while simultaneously undergoing a significant reduction in the return on assets and equity (Cichowicz, Nowak, 2021). Additionally, there was a risk of internal conflicts of interest arising from excessive government involvement. This was not merely a matter of controlling half of the banking sector's capital and simultaneously influencing the authorities of supervisory institutions, namely the KNF and the NBP. It also involved acting as both the main borrower of the banking system and the main guarantor of financial support for entities most severely affected by the pandemic (Ostrowska, 2021).

The year of the pandemic outbreak was distinguished by a notable decline in the overall efficiency of the banking sector. The ratios of ROE, ROA, interest and commission margins exhibited a decline in value, which was attributable to a number of factors, including the reduction in interest rates. This resulted in a corresponding reduction in the profits earned by banks. Additionally, unfavourable increases in the C/I (cost-to-income) ratios and the charge to total operating income were observed, resulting from impairment. This was caused by elevated costs associated with the deterioration of the quality of the loan portfolio and the necessity to augment provisions and write-offs for non-performing loans (Ostrowska, 2021).

The outbreak of the pandemic and the significant reduction in business activity of companies gave rise to concerns that banks might reduce lending to a greater extent than was necessary, thereby precipitating a credit crunch, this is "an extraordinary, excessive reduction in the supply of credit, a mismatch between the supply of credit and rational demand" (Czechowska et al., 2022). Nevertheless, this risk has not materialised. Despite a temporary cessation in the growth of credit extended to households, by the end of 2020 there was already a discernible increase in housing loans (the consequence of low interest rates), which subsequently had an adverse impact on banks due to the government's credit vacation programme when interest rates subsequently rose. Prior to the pandemic, loans to businesses were already at a low level due to the low level of investments made by businesses. During the pandemic period, the percentage of applications rejected decreased, which was an effect of the Bank of National Economy's (pol. Bank Gospodarstwa Krajowego – BGK) guarantee for businesses. In 2020, loan loss write-offs increased, but this was not a phenomenon of a scale that could threaten lending. Following the conclusion of the initial three-month period of 2021, the outlook for the banking sector was already characterised by a notable degree of optimism. The risks identified as potential threats were not the consequences of the pandemic itself, but rather the legal risks associated with foreign currency mortgages (Czechowska et al., 2022) and the accumulated tax and contribution burden imposed on the banking sector. Furthermore, the banking sector exhibited a higher level of exposure than other European Union countries to increases in Treasury bond yields, which could potentially trigger a government-banking loop limiting the ability of some banks to meet capital requirements (Lusztyn, 2022).

The impact of the outbreak of war in Ukraine on financial markets has been likened by Krzysztof Borowski to the impact of other significant historical events, including the eruptions of World War I and World War II, the 1986 Chernobyl nuclear reactor explosion, the September 11, 2001 terrorist attack on the World Trade Center, and Britain's exit from the European Union (Borowski, 2022). The aforementioned geopolitical factors resulted in a decline in stock market indices and an increase in commodity prices. However, it is notable that these changes were not uniform. In the context of the stock market, for instance, the valuation of companies operating within the arms industry may experience an increase, whereas the rise in commodity prices has had a more pronounced impact on those originating from countries affected by conflict. In Poland, following the Russian troop incursion into Ukraine on 24 February 2024, a similar pattern emerged. Six months after the outbreak, the indexes of the Warsaw Stock Exchange exhibited a notable decline relative to the day before the outbreak of the war. The WIG 20, WIG, WIG 40, and WIG 80 all demonstrated a reduction in value, with the WIG 20 declining by 25%, the WIG by 19%, the WIG 40 by 17%, and the WIG 80 by 10%. However, the declines were not uniform across all companies. On 7 March, the nadir of the initial decline was reached. At this juncture, the banking sector was the most adversely affected - Millennium (-20.79%) since 23 February, Alior (-9.59%), Pekao (-7.36%), and PKO BP (-7.09%). In contrast, coal companies experienced notable price increases over the same period, with Bogdanka rising by 98.54% and JSW by 87.55%. The prices of other commodity companies also exhibited growth, albeit to a lesser extent than the aforementioned two (Borowski, 2022).

In the precious metals market, the price of gold, after an initial rise since 8 March, entered a medium-term downward trend, diverging from the experience of previous geopolitical crises. This trend was observed in other metals, with the exception of nickel, of which Russia is the main producer and whose quotations have been suspended. In the energy commodities market, the most significant price increases over the six-month period following the outbreak of the war were observed in the case of natural gas, with prices reaching 100% higher than those recorded prior to the war. The price of diesel fuel increased by approximately 35%, while the prices of crude oil and heating oil, after a period of increases, returned to their pre-war levels in August 2022. In the agricultural products market, the outbreak of war resulted in a notable surge in the prices of wheat, corn, and rice. The prices of these commodities fell below the level recorded in early February only in early summer, coinciding with the commencement of the harvesting season. However, by the end of August, they had risen once more to reach the level recorded on the day the war commenced. The war also had an impact on the value of the Polish currency. In accordance with the principle that the closer a country is to a conflict, the greater the risk investors assign to it, the Polish Zloty weakened by approximately 20% against the US Dollar, by approximately 13% against the Swiss Franc and by approximately 4% against the Euro over a six-month period (Borowski, 2022).

The level of deposits recorded by banks in the six months following the outbreak of war was lower than would have been the case had a forecast been made that did not take the outbreak of war into account. Conversely, the value of loans granted was slightly higher than what the forecast would have indicated. Pawel Wegrzyn and Anna Topczewska employed a vector autoregression model to ascertain the projected value of the deposit-to-loan ratio in the absence of war, which they determined to be 1.34. In reality, the ratio was 1.27. Therefore, the shift did not endanger the stability of the banking sector. However, there was a discernible decline in bank customers' savings and an uptick in their indebtedness, which may have been driven by the surge in energy resource and fuel prices (Wegrzyn, Topczewska, 2023). In response to this situation, banks in Central and Eastern Europe demonstrated heightened risk sensitivity, evidenced by a shift towards safer investments and a deterioration in financial condition (Karas, 2024).

3. Research methodology

The following comparative analysis encompasses 19 banks that operated as joint-stock companies in Poland throughout the period from 2019 to 2023. These banks were not specialised in the sense that they did not focus on specific areas such as car or mortgage banking. Furthermore, banks that were undergoing the bankruptcy process were excluded from the analysis. The objective was to create a group of banks that were experiencing a similar set of circumstances. This approach helps to isolate the impact of external factors, such as market shocks caused by pandemics and war, on the financial performance of the banks under consideration.

The two association banks, BPS and SGB, and Deutsche Bank Polska, which is a bank that caters exclusively to business clients, stand out as the most distinctive in the group under examination.

Of the aforementioned group, five banks were under state control, 11 were under the control of a foreign investor, and three were under the control of a Polish non-state investor. A comprehensive list of the banks included in the survey, accompanied by detailed information regarding their principal owners, is provided in Table 1. It should be noted that the following non-specialist banks operating as joint-stock companies during the period under review are not included in this group: Bank BPH, for which financial results are absent for the majority of the years in question in the Orbis database; Bank Nowy, which was undergoing a period of restructuring during the period under analysis and whose data is also not in the Orbis database; Getin Noble Bank, which was in a state of bankruptcy at the time; and Velo Bank, which was formed during the forced restructuring process of Getin Noble Bank.

A comparative analysis was employed to substantiate the hypotheses, with two indicators considered for each hypothesis. The efficiency of the financial institution was gauged by employing cost efficiency ratios (C/I) and the amount of interest margin (NIM). The profitability of the institution was evaluated at the level of equity (ROE) and assets (ROA). The commitment to lending was assessed through the loan-to-deposit (L/D) ratio and the non-performing loan (NPL) ratio, which provided insight into the quality of the lending activity conducted.

Table 1.

Banks and their owners included in the comparative analysis

no.	Bank	Major shareholder 2019-2024	Characteristics of the main shareholder
1	Alior Bank	PZU (share: 31.91-31.93%)	State Treasury Company
2	Bank BPS	Zrzeszenie Banków Spółdzielczych	Polish cooperative institution
3	Bank Handlowy w Warszawie	Citibank Overseas Investment Corporation	Private company from the US
4	Bank Millennium	Banco Comercial Português	Private company from Portugal
5	Bank Ochrony Środowiska	Narodowy Fundusz Ochrony Środowiska i Gospodarki Wodnej (share: 58.05%)	State institution
6	Bank Poczty	Poczta Polska (share: 75%)	State Treasury Company
7	Bank Polska Kasa Opieki	PZU (share: 20%), Polski Fundusz Rozwoju (udział: 12.80%)	State Treasury companies
8	BNP Paribas Bank Polska	BNP Paribas	Private company from France
9	Credit Agricole Bank Polska	Crédit Agricole	Private company from France
10	Deutsche Bank Polska	Deutsche Bank	Private company from Germany
11	DNB Bank Polska	DNB Bank	Private company from Norway
12	ING Bank Śląski	ING Bank	Private company from the Netherlands
13	mBank	Commerzbank	Private company from Germany
14	Nest Bank	Porto Group Holdings Limited	Private company from Malta
15	Plus Bank	Zygmunt Solorz through the Cypriot company Karswell	Private Cypriot company with Polish owner
16	PKO Bank Polski	Ministerstwo Finansów (share: 29.43%)	Polish Government
17	Santander Bank Polska	Banco Santander	Private company from Spain
18	Santander Consumer Bank	Banco Santander	Private company from Spain
19	SGB Bank	Banki spółdzielcze	Polish cooperative institution

Note: bold - banks under state control.

Source: own compilation based on: KNF. Banking Sector Entities, https://www.knf.gov.pl/podmioty/Podmioty_sektora_bankowego/Banki_w_formie_spolek_akcyjnych, 10.08.2024, and the Orbis database, <https://login.bvdinfo.com/R0/Orbis>, 10.08.2024.

4. Results

4.1. Comparison of effectiveness

In 2019, the mean value of the cost efficiency ratio for the group of banks under analysis was 64.06%. The mean value for banks under state ownership and control was found to be 59.40%, while the mean value for private banks was 65.73%. Notwithstanding the discrepancy in the mean value, the individual state-owned banks did not exhibit any distinctive characteristics within the entire analysed group, as evidenced by the markedly disparate results. The most cost-efficient banks at the time were those included in the Santander group and ING Bank Śląski, while the least efficient were Plus Bank, Deutsche Bank Polska and Bank BPS. In terms of efficiency, state-owned banks were ranked fifth, sixth, seventh, twelfth and fourteenth. Table 2 presents the L/D ratio for all banks under analysis from 2019 to 2023.

Table 2.

Values of the cost-effectiveness index for the period 2019-2023

no.	Bank	Cost effectiveness C/I (%)				
		2019	2020	2021	2022	2023
1	Alior Bank	53.25	59.67	52.51	54.13	41.96
2	Bank BPS	87.87	82.11	76.35	98.88	71.63
3	Bank Handlowy w Warszawie	59.71	65.94	56.73	42.57	36.35
4	Bank Millennium	58.42	60.6	57.32	61.39	33.75
5	Bank Ochrony Środowiska	64.99	119.18	70.32	69.86	80.91
6	Bank Pocztowy	70.32	75.49	76.58	67.51	48.73
7	Bank Polska Kasa Opieki	55.74	58.05	56.43	55.97	41.36
8	BNP Paribas Bank Polska	71.74	63.21	61.85	66.36	50.13
9	Credit Agricole Bank Polska	72.56	80.89	75.3	75.51	77.47
10	Deutsche Bank Polska	88.25	184.91	268.74	158.1	201.97
11	DNB Bank Polska	69.17	62.38	140.36	119.54	211.08
12	ING Bank Śląski	50.83	52.32	51.12	55.73	40.95
13	mBank	59.98	51.84	51.83	53.27	37.03
14	Nest Bank	51.58	55.61	57.3	53.32	62.93
15	Plus Bank	91.12	125.9	102.34	81.35	68.33
16	PKO Bank Polski	52.68	94.11	49.22	64.37	59.83
17	Santander Bank Polska	50.43	52.86	49.19	58.23	51.12
18	Santander Consumer Bank	43.76	48.03	40.66	37.89	37.42
19	SGB Bank	64.76	67.67	73.23	74.41	73.64
	Average	64.06	67.64	62.25	62.99	53.74
	State averages	59.40	81.30	61.01	62.37	54.56
	Private average	65.73	61.96	62.77	63.24	53.40

Note: bold - banks under state control, shaded - outlier observations not included.

Source: own compilation based on data from the Orbis database.

Following the onset of the pandemic in 2020, the mean value of the cost efficiency ratio increased to 76.88%. The rate of change was markedly higher in the group of state-owned banks, reaching an average value of 81.30%, compared to the group of private banks, which reached 75.31%. Bank Ochrony Środowiska was among the three banks with the highest cost-to-income ratio, at 119.18%. This was closely followed by PKO BP, which had a ratio of

94.11%. Both banks were among the three institutions exhibiting the most rapid growth in the C/I ratio. The ratio increased by 78.64% for PKO BP and by 83.38% for BOŚ, with Deutsche Bank Polska exhibiting the highest percentage increase at 109.53%. Not a single state-controlled bank was among the four that managed to reduce their cost/income ratio during this challenging period. The aforementioned process did not occur until the following year, when PKO BP and BOŚ were the banks that exhibited the most pronounced reduction in the value of the cost efficiency ratio. PKO BP demonstrated a reduction of 47.70%, while BOŚ exhibited a reduction of 41%. However, in the subsequent year, 2022, PKO BP was once again at the opposite end of the ranking, with the most significant increase in the C/I ratio, at 30.78%. Such considerable fluctuations in the ratio's value over subsequent years positioned both banks within the top five institutions exhibiting the highest degree of volatility.

Since 2021, the average value of this indicator remained lower in the group of state-owned banks, which was influenced by two private banks whose results significantly lagged behind the rest of the examined group. These are Deutsche Bank Polska and DNB Bank Polska, where the values of the indicator exceeded not only 100%, but also 200%. After the removal of these two outlier observations, the discrepancy between state-owned and private banks is reduced to one percentage point. In both 2021 and 2022, state-owned banks demonstrated superior performance, while in 2023, private banks exhibited enhanced performance.

In 2022, when the war in Ukraine commenced, the values of the indicator exhibited the least significant change over the entire analysed period. Based on the aforementioned analysis, it is not possible to conclude that this event had an impact on the cost efficiency of banks.

Prior to the advent of the pandemic at the conclusion of 2019, the mean interest margin for the surveyed cohort of banking institutions was 3.52%. The mean value was found to be 3.38% for banks under state control and 3.57% for private banks. However, the margins of Nest Bank and Santander Consumer Bank were markedly higher than those of the other institutions and were identified as outlier observations in 2019, 2020 and 2021. In 2022, only Nest Bank's margin should be considered an outlier; in 2023, there are no outlier observations. Following the removal of the outlier observations, the average margin in 2019 was found to be 2.93%, with private banks exhibiting a lower average margin of 2.75%. Table 3 presents the margins of all banks analysed from 2019 to 2023.

Prior to the advent of the pandemic, BOŚ exhibited the lowest interest margin among state-controlled banks, at 2.39%, and was the fifth lowest in the group under analysis. The remaining state-owned banks were situated between 10th and 15th on the list, with Alior Bank exhibiting an interest margin of 4.49%. The lowest value recorded at the time was observed in Deutsche Bank Polska at 1.01%, while the highest was observed in Nest Bank at 9.11%. The highest not-outlier value of the interest margin was observed in Credit Agricole Bank Poland, reaching 5.31%.

Table 3.*The amount of interest margin in 2019-2023*

no.	Bank	Interest margin (NIM)				
		2019	2020	2021	2022	2023
1	Alior Bank	4.49	3.88	3.68	4.57	5.81
2	Bank BPS	1.35	1.22	1.04	1.01	1.24
3	Bank Handlowy w Warszawie	2.69	2.00	1.47	4.57	4.79
4	Bank Millennium	2.86	2.76	2.83	3.40	4.87
5	Bank Ochrony Środowiska	2.39	2.00	1.94	3.81	3.93
6	Bank Pocztowy	3.63	2.83	2.44	5.01	5.91
7	Bank Polska Kasa Opieki	3.00	2.51	2.45	3.30	4.36
8	BNP Parisbas Bank Polska	3.09	2.86	2.66	2.61	3.55
9	Credit Agricole Bank Polska	5.31	4.37	3.80	4.27	5.27
10	Deutsche Bank Polska	1.01	0.92	0.64	2.39	3.23
11	DNB Bank Polska	1.54	1.45	1.23	1.31	4.37
12	ING Bank Śląski	2.92	2.68	2.61	2.75	3.66
13	mBank	2.86	2.52	2.35	3.23	4.79
14	Nest Bank	9.11	7.34	6.49	7.59	7.25
15	Plus Bank	4.73	3.17	2.79	6.43	7.46
16	PKO Bank Polski	3.37	3.06	2.64	2.89	4.22
17	Santander Bank Polska	3.41	2.86	2.68	4.12	5.23
18	Santander Consumer Bank	7.95	6.47	6.29	7.17	6.46
19	SGB Bank	1.21	1.14	1.02	1.05	1.09
	Average	2.93	2.48	2.25	3.55	4.60
	State averages	3.38	2.86	2.63	3.92	4.85
	Private average	2.75	2.33	2.09	3.41	4.52

Note: bold - banks under state control, shaded - outlier observations not included.

Source: own compilation based on data from the Orbis database.

In 2020, the outbreak of the pandemic was not the sole factor responsible for the decline in interest margins across the entire group of banks under analysis. Additionally, the decision of the National Bank of Poland, taken in an effort to mitigate the economic impact of the pandemic, resulted in interest rates being lowered to an unprecedentedly low level. The most modest decline in the interest margin was observed in the case of Bank Millennium, amounting to 3.5%. Conversely, Plus Bank exhibited the most pronounced reduction, with a 32.98% decrease. Among state-owned banks, the interest margin exhibited the least pronounced decline at PKO BP, with a reduction of 9.20%, representing the seventh lowest rate of decline. The decline dynamics of Alior Bank were 13.59%, while BOŚ declined by 16.32%, Pekao by 16.33%, and Bank Pocztowy by 22.04%. State-owned banks, which were among the higher-margin banks prior to the pandemic, subsequently exhibited the most pronounced margin shrinkage following the onset of the pandemic.

The mean margin for the entire analysed group, excluding outliers, was 2.48% in 2020. For state-owned banks, the mean was higher at 2.86%, while for private banks it was lower at 2.33%.

In the year 2021, the interest margin of Bank Millennium exhibited a 2.54% increase, representing the sole instance of such an increase among the sampled banks. The remaining banks exhibited a decline in their interest margins, with the greatest reduction observed at Deutsche Bank Polska (30.43%) and the smallest at Pekao (2.38%). In addition to Pekao,

the remaining state-owned banks can be divided into two groups in terms of the decline in interest margin. BOŚ and Alior Bank exhibited a slight decrease in the margin, with reductions of 3% and 5.15%, respectively. In contrast, PKO BP and Bank Pocztowy demonstrated a continued dynamic reduction in the interest margin, with declines of 13.73% and 13.78%, respectively. When considering the absolute values of the margin, state-owned banks did not exhibit any distinctive characteristics compared to private banks, with varying values observed.

The year of the outbreak of war was characterised by a rapid increase in interest margins at all banks with the exception of BNP Paribas and Bank BPS. This was a consequence of the National Bank of Poland's decision to increase interest rates in response to the rise in inflation, which accelerated as a result of rising commodity and fuel prices. The growth in interest margins was more pronounced among state-owned banks other than PKO BP. The Postal Bank achieved the fourth highest growth rate at 105.33%, while BOŚ attained the fifth highest growth rate at 96.39%. Pekao and Alior Bank achieved the eighth and ninth highest growth rates, at 34.69% and 24.18%, respectively. PKO BP, with a growth rate of 9.47%, was in 14th place in terms of interest margin growth. The growth rate of average values in both groups was higher in private banks.

The mean margin level for the group of banks surveyed in 2022 was 3.55%. The mean value for state-owned banks was higher at 3.92%, while that for private banks was lower at 3.41%. Over the past year, banks have observed a further increase in interest margins, with the mean rising to 4.60 for the entire group, 4.85 for government-controlled banks, and 4.52 for private banks.

A comparison of the values and dynamics of changes occurring on the two efficiency indicators in 2019-2023 allows us to conclude that, with regard to the cost efficiency indicator, state-owned banks did not demonstrate a superior performance compared to private banks. However, the average value of the interest margin was consistently higher in state-owned banks throughout the period. A comparison of the subsequent years reveals further differences in the dynamics of change. State-owned banks exhibited higher volatility than private banks in the cost efficiency ratio, as evidenced by the larger increases following the outbreak of the pandemic and the more dynamic decreases the following year. Similarly, in terms of the interest margin after the outbreak of the pandemic, banks under state ownership control were among those in which the margin fell more dynamically.

4.2. Profitability comparison

Prior to the advent of the pandemic in 2019, the mean return on assets (ROA) of the banking institutions under examination was 0.45%. The mean value for state-owned banks was higher, at 0.65%, while that for private banks was 0.38%. However, the value of the indicator for two banks exhibited characteristics that were inconsistent with the overall distribution, suggesting that they may represent outlier observations. Notably, Nest Bank exhibited a high negative profitability of -2.81%, while Santander Bank Consumer demonstrated a high positive

profitability of 2.60%. Excluding the two outliers, the average profitability of the study group prior to the pandemic increased to 0.52%, with private banks reaching 0.46%. This indicates that the average profitability of the state-owned bank group remained higher. The superior profitability of state-owned banks relative to private banks was largely attributable to the performance of two specific institutions: PKO BP (1.2%) and Pekao (1.10%). These two institutions were the second and fourth most successful performers within the analysed group. The profitability of the remaining three state-owned banks positioned them among those with low but nevertheless positive ROA values. In addition to Nest Bank, two other banks, namely Plus Bank and Bank BPS, exhibited negative profitability prior to the pandemic. Table 4 presents the ROA values for all banks over the period 2019-2023.

Following the onset of the pandemic, the return on assets of 17 of the 19 banks under analysis exhibited a decline. Only Nest Bank, which reduced its negative yield from 2.81% to 2.01%, and BNP Paribas, whose yield rose from 0.56% to 0.64%, demonstrated resilience by avoiding the declines. The asset yield declines observed among state-owned banks were particularly pronounced. The largest decline within this group was recorded by BOŚ, which declined by 502.56%, representing the third largest decline. Alior Bank experienced a decline of 221.21%, PKO BP a decline of 157.17%, and Bank Pocztowy a decline of 145.83%. Among the state-owned banks, only Pekao exhibited a decline in its return on assets that did not exceed 100%, at 53.64%. Consequently, this bank was the sole member of the group of state-owned banks to record a positive return on assets in 2020, at 0.51%, which was the fifth best result.

This was reflected in the average return on assets of the group under study. In the period under analysis, the only year in which the average return on assets of state banks was lower than that of private banks was 2020. The average profitability of the entire group was -0.24%, with state-owned banks exhibiting a lower average of -0.46% and private banks a higher average of -0.16%. No outlier observations were identified.

In the subsequent year, state-controlled banks were among the institutions that exhibited the most rapid growth in asset efficiency. The Postal Bank exhibited the second highest rate of return on assets (ROA) growth, with a growth rate of 409.09%. PKO BP and Alior Bank demonstrated the fourth and fifth highest growth rates, at 273.24% and 250%, respectively. BOŚ exhibited the seventh highest growth rate, at 114.65%. Pekao demonstrated the ninth highest growth rate, at 76.47%.

The mean ROA for the entire group, after the exclusion of one outlier observation (i.e., Deutsche Bank Polska's negative margin of 2.62%), was 0.24%. The corresponding figures for banks under state control and for private banks were 0.66% and 0.07%, respectively. The dynamic increases in the profitability of state-owned banks' assets resulted in elevated values of this indicator in 2021 in comparison to the analysed group. PKO BP achieved the highest profitability at 1.23%, while Pekao attained the fourth-highest result at 0.90%. Alior Bank was in sixth place with a profitability rate of 0.60%, and Bank Pocztowy was in

eighth place with a rate of 0.34%. BOŚ was in ninth place with a rate of 0.23%. Among private banks, five institutions had negative profitability.

Table 4.

Return on assets (ROA) ratios for 2019-2023

no.	Bank	ROA %				
		2019	2020	2021	2022	2023
1	Alior Bank	0.33	-0.40	0.60	0.82	2.35
2	Bank BPS	-0.21	0.02	0.16	-0.15	0.27
3	Bank Handlowy w Warszawie	0.95	0.31	1.17	2.35	3.15
4	Bank Millennium	0.63	0.02	-1.32	-0.94	0.49
5	Bank Ochrony Środowiska	0.39	-1.57	0.23	0.61	0.36
6	Bank Pocztowy	0.24	-0.11	0.34	1.19	2.55
7	Bank Polska Kasa Opieki	1.10	0.51	0.9	0.65	2.24
8	BNP Parisbas Bank Polska	0.56	0.64	0.14	0.31	0.65
9	Credit Agricole Bank Polska	0.29	-0.54	0.12	0.13	0.39
10	Deutsche Bank Polska	0.03	-1.83	-2.62	-2.19	-3.26
11	DNB Bank Polska	0.58	0.44	-0.46	-0.65	-5.85
12	ING Bank Śląski	1.10	0.77	1.19	0.82	1.92
13	mBank	0.66	0.06	-0.62	-0.34	0.01
14	Nest Bank	-2.81	-2.01	0.03	0.74	0.09
15	Plus Bank	-0.35	-2.16	-0.94	4.62	4.63
16	PKO Bank Polski	1.20	-0.71	1.23	0.78	1.18
17	Santander Bank Polska	1.17	0.56	0.53	1.20	1.85
18	Santander Consumer Bank	2.60	1.46	0.89	2.07	0.36
19	SGB Bank	0.12	0.03	0.05	0.09	0.09
	Average	0.52	-0.24	0.24	0.57	1.33
	State averages	0.65	-0.45	0.66	0.81	1.71
	Private average	0.46	-0.16	0.07	0.47	1.16

Note: bold - banks under state control, shaded - outlier observations not included.

Source: own compilation based on data from the Orbis database.

In the subsequent years, state-owned banks exhibited elevated return on assets (ROA) ratios relative to the surveyed group. However, this distinction was not as pronounced as it had been in 2021, with the rankings shifting towards the midpoint. In both 2022 and 2023, no state-owned banks recorded a negative return on assets, whereas some private banks did so. The highest return on assets among state banks was achieved by Bank Pocztowy, and the lowest by BOŚ. With regard to the rate of change of the ratio in 2022, 2023 and its volatility throughout the period, state banks did not exhibit any distinctive characteristics in comparison to private banks.

With regard to the return on equity (ROE) ratio, the circumstances were comparable to those observed in the ROA during the period under examination. The profitability of state-owned banks was higher on average in all years except 2020, when it was lower. In addition, they reacted more dynamically to the outbreak of the pandemic than private banks, both in terms of decline and increase. As with ROA, the impact of the outbreak of war in Ukraine is not visible in terms of the value of the indicator or its changes. Table 5 presents the ROE values for all banks over the period 2019-2023.

Table 5.*Return on equity (ROE) ratios in 2019-2023*

no.	Bank	ROE (%)				
		2019	2020	2021	2022	2023
1	Alior Bank	3.76	-4.68	7.72	11.30	26.33
2	Bank BPS	-5.73	0.72	4.86	-4.38	9.07
3	Bank Handlowy w Warszawie	6.80	2.35	9.59	20.15	25.51
4	Bank Millennium	6.47	0.25	-16.87	-16.64	9.29
5	Bank Ochrony Środowiska	3.32	-14.92	2.51	6.70	3.81
6	Bank Pocztowy	3.12	-1.47	5.98	25.58	36.32
7	Bank Polska Kasa Opieki	9.38	4.51	8.82	7.37	24.78
8	BNP Paribas Bank Polska	5.66	6.32	1.51	3.90	8.39
9	Credit Agricole Bank Polska	2.35	-4.80	1.25	1.56	4.18
10	Deutsche Bank Polska	0.25	-15.22	-27.06	-32.12	-52.87
11	DNB Bank Polska	3.73	3.20	-3.10	-2.62	-13.71
12	ING Bank Śląski	11.62	7.91	14.36	14.99	34.04
13	mBank	6.45	0.63	-7.76	-5.32	0.18
14	Nest Bank	-29.78	-22.67	0.37	8.15	1.03
15	Plus Bank	-54.7	-152.71	-116.08	88.99	34.60
16	PKO Bank Polski	10.00	-6.29	12.56	9.02	13.60
17	Santander Bank Polska	9.12	4.45	4.48	10.81	15.92
18	Santander Consumer Bank	15.65	8.39	4.50	9.68	1.69
19	SGB Bank	3.63	0.98	1.66	2.63	2.62
	Average	5.62	-0.45	3.08	6.05	13.20
	State averages	5.92	-4.57	7.52	11.99	20.97
	Private average	5.50	1.27	1.24	3.58	10.22

Note: bold - banks under state control, shaded - outlier observations not included.

Source: own compilation based on data from the Orbis database.

In calculating the average values of the indicator for the group of banks under analysis for the period 2019-2022, two outlier observations were excluded from each year and one observation in 2023. The banking institution whose return on equity (ROE) performance exhibited the greatest divergence from the median within the group was Plus Bank. It exhibited the highest negative ROE in 2019-2021 and the highest positive ROE in 2022, and was only included in the calculation in 2023. Deutsche Bank Polska also demonstrated a high negative ROE and was classified as an outlier in 2021-2023. Similarly, Nest Bank's result in 2019-20 was not included for the same reason.

Prior to the advent of the pandemic, the mean yield for the cohort of banks under consideration was 5.62%. Following a decline due to the pandemic and associated shifts in interest rate policy, the mean yield reached a higher level in 2022. In the case of state-owned banks, the average before the pandemic was higher, at 5.92. There was a significant decline in 2020, reaching -4.57%. However, it subsequently rose above the baseline in 2021, reaching 7.52%. Over the following two years, it continued to rise, reaching 20.97%. In the case of private banks, attaining a return on equity above the baseline of 5.50% was a considerably lengthier process, occurring only in 2023 when the level reached 10.20%, which was half that of state-owned banks.

A comparison of the profitability ratios of state-controlled and private banks reveals that, during the period of two significant economic stimuli, state-owned banks exhibited higher profitability. However, they demonstrated less resilience to the initial stimulus, namely the pandemic, than their private counterparts.

4.3. Comparison of lending

Prior to the advent of the pandemic, the mean ratio of loans granted to deposits acquired by banks (L/D) was slightly higher in state-owned banks, at 82.25% compared to 81.65%. In the following years, this ratio in both groups of banks exhibited a gradual decline, albeit at a more pronounced rate in private banks. The disparity between the averages of the two groups, which was 0.60 p.p. in 2019, widened to 7.60 p.p. in 2023.

The banking institutions that demonstrated the least propensity to extend credit throughout the observation period were those established by cooperative associations, namely SGB Bank and Bank BPS. At the opposite end of the spectrum was Santander Consumer Bank, which, with the exception of 2021, exhibited the highest L/D ratio values. Among banks under state control, the initial leader, PKO BP, was replaced by Alior Bank, which exhibited the lowest reduction in the loan-to-deposit ratio. Throughout the period, Bank Pocztowy and BOŚ maintained the lowest ratio among state-owned banks. The full set of indicator values is shown in Table 6.

The most pronounced decline in the mean values of the L/D ratio was observed in 2020 and 2022, which coincided with the onset of the pandemic and the war in Ukraine. The mean value for the entire group decreased by 12.61% in 2020 and by 10.90% in 2022. By way of comparison, the decline in 2021 was 4.11%, while in 2023 the percentage change was 6.39%. In the initial year of the pandemic, state-owned banks reduced their loan-to-deposit ratio by 10.54%, while private banks reduced theirs by 12.61%. In the second year of the pandemic, there was a greater reduction in the average loan-to-deposit ratio for state banks than for private banks, with the former reducing theirs by 4.21% and the latter by 4.02%. However, a notable discrepancy in banks' capital allocation to lending emerged in the year of the war in Ukraine. In 2022, the mean L/D ratio in state-owned banks decreased by 5.81%, while in private banks it declined by 12.96%.

Table 6.*Ratios of loans granted to deposits acquired (L/D) in 2019-2023*

no.	Bank	Loans to deposits L/D (%)				
		2019	2020	2021	2022	2023
1	Alior Bank	85.05	83.08	80.36	81.22	80.94
2	Bank BPS	36.31	31.25	34.61	27.77	21.86
3	Bank Handlowy w Warszawie	52.34	41.57	41.92	36.87	32.32
4	Bank Millennium	84.33	88.92	85.74	77.60	68.31
5	Bank Ochrony Środowiska	77.39	68.74	65.98	58.67	57.76
6	Bank Pocztowy	72.03	59.69	54.22	51.69	47.14
7	Bank Polska Kasa Opieki	87.55	78.26	80.02	72.21	68.38
8	BNP Parisbas Bank Polska	84.90	81.44	83.18	73.06	66.89
9	Credit Agricole Bank Polska	83.11	75.38	74.14	74.54	78.20
10	Deutsche Bank Polska	63.92	60.01	59.73	33.51	39.63
11	DNB Bank Polska	77.56	68.06	112.62		
12	ING Bank Śląski	88.82	79.51	82.55	80.10	75.64
13	mBank	89.25	78.60	73.21	67.54	60.25
14	Nest Bank	83.12	75.20	66.46	55.80	44.45
15	Plus Bank	69.87	55.71	44.06	51.57	46.69
16	PKO Bank Polski	89.25	78.11	71.84	68.14	61.04
17	Santander Bank Polska	90.03	81.03	79.15	75.84	75.13
18	Santander Consumer Bank	112.56	110.94	104.19	103.70	96.42
19	SGB Bank	20.12	18.59	17.24	17.02	15.02
	Average	81.83	71.97	69.01	61.49	57.56
	State averages	82.25	73.58	70.48	66.39	63.05
	Private average	81.65	71.36	68.49	59.61	55.45

Note: bold - banks under state control, shaded - outlier observations not included.

Source: own compilation based on data from the Orbis database.

The considerable discrepancy observed may be attributed to the elevated risk profile associated with Poland as a market situated in proximity to countries engaged in armed conflict. In light of these considerations, it may be anticipated that banks with foreign shareholders will curtail their involvement in financing both companies and households. The bank that reduced its loan-to-deposit ratio the most in 2022 was Deutsche Bank Polska, which provides banking services exclusively to companies, with a reduction of 43.90%. The ratio was reduced to 33.51%, which constituted the lowest L/D ratio observed in the analysed group, with the exception of the two banks established by cooperatives, which maintained this ratio at the lowest level throughout the analysed period. The next bank to decrease the L/D ratio the most in 2022 was Bank BPS, a cooperative-dependent institution, which reduced its ratio by 19.78%. This was followed by three foreign-dependent banks: Nest Bank, which decreased its ratio by 16.04%; BNP Parisbas, which decreased its ratio by 12.17%; and Bank Handlowy, which decreased its ratio by 12.05%. However, the subsequent two banks were already state-dependent institutions: BOŚ, with a reduction of 11.08%, and Pekao, with a reduction of 9.76%. The banks that increased their loan-to-deposit ratio in 2022 were Plus Bank, whose main shareholder is registered in Cyprus but is owned by Polish businessman Zygmunt Solorz, by 17.04%; state-dependent Alior Bank, by 1.07%; and Credit Agricole with a French shareholder, by 0.54%. The modest fluctuations in the index for the final two banks suggest that

neither institution modified its credit policy during that period. Furthermore, even after the index increase, Plus Bank remained within the lowest index level group.

Additionally, the elevated loan-to-deposit ratio observed in state-owned banks was accompanied by a notable increase in the proportion of non-performing loans within the overall loan portfolio, as indicated by the ratio of non-performing loans (NPL) to total loans. In 2019, the mean ratio for the entire group of banks under analysis was 7.88%. The ratio was higher in state-owned banks (9.83%) than in private banks (6.98%). Subsequently, each of these averages exhibited an increase following the advent of the pandemic, with the private bank group demonstrating a more pronounced surge of 9.31%, in comparison to the state bank group, which exhibited a more modest increase of 4.17%. In the subsequent year, the mean proportion of non-performing loans declined by over 11% in both groups. However, the situation in both groups diverged significantly in 2022 and 2023. In 2022, the average NPL in state-owned banks increased by 2.43%, whereas in private banks it decreased by 21.97%. In 2023, the average NPL in state-owned banks decreased by 11.09%, while in private banks it remained relatively stable, with a slight decrease of 0.89%. The NPL values are presented in Table 7.

The bank with the poorest quality loan portfolio was Plus Bank, where the majority of loans were non-performing, and the value of the ratio increased consistently throughout the analysed period, from 54.62% in 2019 to 79.52% in 2023. This was an extremely anomalous observation and was thus excluded from the calculation of the mean value. Furthermore, in the 2022-23 period, the ratio value at Nest Bank, where it was 25.28% and 27.68%, respectively, was also classified as an anomalous observation.

The NPL ratio values of state-owned banks did not exhibit a distinctive profile compared to private banks. However, in 2020, there was a discernible trend whereby these banks were among those with higher ratio values, with the exception of PKO BP, which had the third lowest score.

With regard to the rate of change of NPLs, banks under state control in 2020 exhibited the lowest rate of change of the indicator, with the exception of Bank Pocztowy, where it increased by 13.09%, representing the fifth highest rate of change. In 2021, the proportion of non-performing loans decreased across all state-owned banks. In 2022, state-owned banks demonstrated a comprehensive diversification, exhibiting results across the full range of values observed in the entire group of analysed banks. This included a decrease of 16.65% in Alior Bank, representing the second-largest decline in NPLs, and an increase of 24.40% in Pekao, representing the second-largest increase in the entire group. In 2023, the value of the index declined for half of the banks, while the other half experienced an increase. State-owned banks were among those reducing the share of non-performing loans. However, Pekao was an exception, with the indicator showing minimal change due to a recorded increase of only 0.30%. Furthermore, state-owned banks demonstrated no distinctive performance in terms of the volatility of the indicator throughout the analysed period when compared to private-owned banks.

Table 7.*Credit portfolio quality indicators (NPL) in 2019-2023*

no.	Bank	Non-performing loans / Gross loans to customers				
		2019	2020	2021	2022	2023
1	Alior Bank	14.53	14.51	11.83	9.86	8.63
2	Bank BPS	13.19	12.63	12.12	12.69	12.52
3	Bank Handlowy w Warszawie	3.72	3.94	4.38	4.20	4.19
4	Bank Millennium	4.47	4.85	4.30	4.39	4.54
5	Bank Ochrony Środowiska	15.21	15.64	13.45	14.82	13.45
6	Bank Pocztowy	9.78	11.06	10.81	11.37	8.99
7	Bank Polska Kasa Opieki	5.55	5.72	5.41	6.73	6.75
8	BNP Paribas Bank Polska	5.75	5.42	3.68	3.28	3.01
9	Credit Agricole Bank Polska	7.36				
10	Deutsche Bank Polska	3.37	5.01	6.17	4.93	6.30
11	DNB Bank Polska			1.23	2.11	2.44
12	ING Bank Śląski	2.92	3.24	2.54	2.26	2.64
13	mBank	4.01	4.44	3.79	3.89	4.16
14	Nest Bank	17.41	19.77	20.39	25.28	27.68
15	Plus Bank	54.62	62.93	68.59	73.30	79.52
16	PKO Bank Polski	4.10	4.26	3.84	3.68	3.49
17	Santander Bank Polska	5.12	5.69	4.91	4.86	4.53
18	Santander Consumer Bank	9.51	11.36	11.12	10.33	8.14
	Average	7.88	8.50	7.50	6.63	6.25
	State averages	9.83	10.24	9.07	9.29	8.26
	Private average	6.98	7.64	6.78	5.29	5.25

Note: bold - banks under state control, shaded - outlier observations not included.

Source: own compilation based on data from the Orbis database.

A comparison of the indicators of banks' asset exposure to lending and the quality of the loan portfolio reveals, in line with existing literature, that state banks play a stabilising role during periods of market shocks. State banks demonstrated a lesser capacity to reduce asset exposure to lending throughout the period, particularly during the emergence of negative impulses, which was most evident following the outbreak of war in Ukraine. This resulted in a deterioration in the quality of the loan portfolio, which is also in line with previous research indicating that state-dependent banks may be more inclined to take higher risks.

5. Conclusions

A comparison of the efficiency, profitability and lending ratios of state-controlled banks to those of privately-owned banks allows us to reject the initial hypothesis that there are no differences in efficiency. Banks under state control demonstrated a higher average net interest margin and a more dynamic response to the pandemic stimulus. Following the onset of the pandemic, both analysed efficiency indicators deteriorated more rapidly in state-owned banks than in private banks, and subsequently improved more rapidly.

Furthermore, an examination of the values and dynamics of changes in profitability ratios indicates that the hypothesis that there are no differences can be rejected. On average, state-owned banks exhibited higher profitability for four of the five years under analysis, both at the level of assets and equity. However, in the year 2020, state banks demonstrated a notable decline in profitability, which then rebounded with equal dynamism in the subsequent year.

The study also permits the unambiguous rejection of the hypothesis that there were no differences between banks under state control and those under the control of private investors in terms of lending during the analysed period. State-owned banks reduced lending to a lesser extent during both the pandemic and the outbreak of the war in Ukraine, which resulted in a deterioration in the quality of their loan portfolio.

A negative verification of the stated hypotheses results in the stated second-order objectives. A distinction can be made between state-owned and private banks with regard to their efficiency and profitability. Nevertheless, it remains unclear whether this differentiation had a positive or negative impact on the stability of the banking sector. While state-owned banks exhibited higher average profitability for four of the five years under analysis, this represented a positive impact. However, the sharp decline in profitability observed in the year of the pandemic outbreak had a destabilising effect. In terms of efficiency indicators, only one consistently exhibited a more favourable average value over four of the years under analysis. However, both indicators exhibited a sharp deterioration in the year of the pandemic outbreak. Therefore, the differentiation in efficiency between banks under state control and those under private control is indicated by only one of the two efficiency indicators considered. Furthermore, the stabilising effect is observed in only its value for most of the period analysed, but not in its resistance to the impulse of the pandemic outbreak.

The second of the second-order objectives was achieved by demonstrating the differentiation between banks dependent on the state and those dependent on private owners in terms of lending. State-owned banks demonstrated a lesser capacity to extend credit during the period of crisis, which had a stabilising effect on the country's economy. However, this strategy had an adverse impact on the quality of the loan portfolio of state-owned banks, with a higher proportion of non-performing loans than in private banks. This had a detrimental effect on the stability of the banking sector.

The verification of the assumption that banks under state control had a stabilising effect on the banking sector and the Polish economy during the outbreak of the COVID-19 pandemic and the war in Ukraine, which was the main objective of the study, yielded results that permit the assumption that state banks had a stabilising effect on the Polish economy. However, this same stabilising effect could potentially exert a negative impact on the stability of the banking sector. Therefore, when examining state capital in the banking sector as a means of implementing state economic policy, it is essential to consider the potential risks this capital may pose to the

stability of the banking sector. A banking crisis is identified as one of the most significant threats to the economy.

In interpreting the results, it should be borne in mind that the survey was conducted on a limited number of banks due to its restriction to a single, national financial market. The restricted number of observations limited the possibility of applying advanced statistical analysis methods. In order to confirm the results, it would be beneficial to expand the group of analysed entities by increasing the geographical scope to include other CEE countries bordering or in close proximity to countries involved in the conflict in Ukraine.

References

1. Barth, J.R., Caprio Jr., G., Levine, R. (2001). Banking systems around the globe: Do regulations and ownership affect performance and stability? In: F.S. Mishkin (Ed.), *Prudential supervision: What works and what doesn't* (pp. 31-96). University of Chicago Press.
2. Beck, T., Demirguc-Kunt, A., Martinez Peria, M.S. (2007). Reaching out: Access to and use of banking services across countries. *Journal of Financial Economics*, Vol. 85, Iss. 1, pp. 234-266, doi: 10.1016/j.jfineco.2006.07.002.
3. Berger, A.N., Clarke, G.R.G., Cull, R., Klapper, L., Udell, G.F. (2005). Corporate governance and bank performance: A joint analysis of the static, selection, and dynamic effects of domestic, foreign, and state ownership. *Journal of Banking & Finance*, Vol. 29, Iss. 8-9, pp. 2179-2221, doi: 10.1016/j.jbankfin.2005.03.013.
4. Bertay, A., Demirgüç-Kunt, A., Huizinga, H. (2015). Bank ownership and credit over the business cycle: Is lending by state banks less procyclical? *Journal of Banking & Finance*, Vol. 50, pp. 326-339, doi: 10.1016/j.jbankfin.2014.03.012.
5. Borowski, K. (2022). Doświadczenia rynków finansowych po ataku Rosji na Ukrainę. In: M. Kaleta, M. Laska, D. Żuchowska (Eds.), *Polityka gospodarcza wobec współczesnych wyzwań* (pp. 35-66). Akademia Kultury Społecznej i Medialnej w Toruniu.
6. Borsuk, M., Kowalewski, O. (2020). Wpływ systemowych zmian własnościowych na stabilność finansową polskiego sektora bankowego. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu*, Vol. 64, No. 5, pp. 18-31, doi: 10.15611/pn.2020.5.02.
7. Brei, M., Schclarek, A. (2013). Public bank lending in times of crisis. *Journal of Financial Stability*, Vol. 9, Iss. 4, pp. 820-830, doi: 10.1016/j.jfs.2013.01.002.
8. Carretta, A., Farina, V., Gon, A., Parisi, A. (2012). Politicians on board: Do political connections affect banking activities in Italy? *European Management Review*, Vol. 9, Iss. 2, pp. 75-83, doi: 10.1111/j.1740-4762.2012.01032.x.

9. Carvalho, D. (2014). The real effects of government-owned banks: Evidence from an emerging market. *The Journal of Finance*, Vol. 69, Iss. 2, pp. 577-609, doi: 10.1111/jofi.12130.
10. Chen, Y-S., Chen, Y., Lin, Ch-Y., Sharma, Z. (2016). Is there a bright side to government banks? Evidence from the global financial crisis. *Journal of Financial Stability*, Vol. 26, pp. 128-143, doi: 10.1016/j.jfs.2016.08.006.
11. Chopra, S. (2022). Czy banki sektora publicznego w Indiach stanowią porażkę rządu? – empiryczna analiza porównawcza banków sektora publicznego i prywatnego. *Analizy i Studia*, Vol. 14 No. 2, pp. 41-53, doi: 10.33119/ASCASP.2022.2.4.
12. Cichowicz, E., Nowak, A.K. (2021). Ocena zmian zachodzących w modelach ALM banków w Polsce po wybuchu pandemii COVID-19. *Bezpieczny Bank*, Vol. 85 No. 4, pp. 79-100, doi: 10.26354/bb.4.4.85.2021.
13. Cole, S. (2009). Financial development, bank ownership, and growth. Or, does quantity imply quality? *The Review of Economics and Statistics*, Vol. 91, Iss. 1, pp. 33-51, doi: 10.1162/rest.91.1.33.
14. Cornett, M.M., Guo, L., Khaksari, S., Tehranian, H. (2010). The impact of state ownership on performance differences in privately-owned versus state-owned banks: An international comparison. *Journal of Financial Intermediation*, Vol. 19, Iss. 1, pp. 74-94, doi: 10.1016/j.jfi.2008.09.005.
15. Cull, R., Martínez Pería, M.S. (2013). Bank ownership and lending patterns during the 2008–2009 financial crisis: Evidence from Latin America and Eastern Europe. *Journal of Banking & Finance*, Vol. 37, Iss. 12, pp. 4861-4878, doi: 10.1016/j.jbankfin.2013.08.017.
16. Cull, R., Martinez Peria, M.S., Verrier, J. (2018). Bank Ownership: Trends and Implications. *World Bank Policy Research Working Paper*, No. 8297. Retrieved from: <https://ssrn.com/abstract=3098574>, 27.08.2024.
17. Czechowska, I.D., Lipiński, Cz., Stawska, J., Zatoń, W. (2022). *Potencjał działalności kredytowej sektora bankowego w obliczu pandemii COVID-19*. Wydawnictwo Uniwersytetu Łódzkiego, p. 7.
18. Dinc, S. (2005). Politicians and banks: Political influences on government-owned banks in emerging markets. *Journal of Financial Economics*, Vol. 77, Iss. 2, pp. 453-479, doi: 10.1016/j.jfineco.2004.06.011.
19. Godula, E. (2001). *Kapitał zagraniczny w polskim sektorze bankowym*. Warszawa: Międzynarodowa Szkoła Menedżerów.
20. Goniszewski, M. (2023). *Kapitał zagraniczny w bankach*. Sopot: Centrum Myśli Strategicznych, p. 60.
21. Gostomski, E., Lepczyński, B. (2019). Zmiany struktury własnościowej sektora bankowego w Polsce. In: L. Kurliński, B. Lepczyński (Eds.), *Polityka państwa wobec sektora bankowego w Polsce. Konsekwencje sektorowe i makroekonomiczne* (pp. 51-71). Warszawa: ALTERUM Ośrodek Badań i Analiz Systemu Finansowego.

22. Iannotta, G., Nocera, G., Sironi A. (2013) The impact of government ownership on bank risk. *Journal of Financial Intermediation*, Vol. 22, Iss. 2, pp. 152-176, doi: 10.1016/j.jfi.2012.11.002.
23. *Informacja na temat sytuacji sektora bankowego w 2020 r.* (2021). Warszawa: Urząd Komisji Nadzoru Finansowego.
24. *Informacja na temat sytuacji sektora bankowego w 2021 r.* (2022). Warszawa: Urząd Komisji Nadzoru Finansowego.
25. *Informacja na temat sytuacji sektora bankowego w 2022 r.* (2023). Warszawa: Urząd Komisji Nadzoru Finansowego.
26. Jastrzębski, J., Machalski, Ł. (2022). Struktury transakcji w ramach przymusowej restrukturyzacji banków. Uwagi ogólne dotyczące strukturyzowania transakcji oraz wnioski z doświadczeń krajowych. *Bezpieczny Bank*, Vol. 87, No. 2, pp. 88-109, doi: 10.26354/bb.5.2.87.2022.
27. Jianga, Ch., Yaob, S., Feng, G. (2013). Bank ownership, privatization, and performance: evidence from a transition country. *Journal of Banking & Finance*, Vol. 37, Iss. 9, pp. 3364-3372, doi: 10.1016/j.jbankfin.2013.05.009.
28. Karaś, M.A., Broda, M. (2024). Stabilność i wyniki finansowe banków w krajach Europy graniczących z konfliktem militarnym w Ukrainie. *Gospodarka Narodowa. The Polish Journal of Economics*, Vol. 318, pp. 64-111, doi: 10.33119/GN/184318.
29. Kawalec, S., Błażuk, K. (2021). *Banki i inwestycje – zagrożenia dla dalszego rozwoju polskiej gospodarki*. Warszawa: Forum Obywatelskiego Rozwoju.
30. Kawalec, S., Gozdek, M. (2012). *Raport dotyczący optymalnej struktury polskiego systemu bankowego w średnim okresie*. Retrieved from: http://www.capitalstrategy.pl/wp-content/uploads/2013/12/CS-Optymalna_struktura_sektora_bankowego-2012-10-31-Ze_streszczeniem.pdf, 7.09.2024.
31. Kirimi, P.N. (2024). Effect of banks' ownership structure on financial performance: evidence from banks in an emerging market. *Measuring Business Excellence*, Vol. 28, No. 1, pp. 137-150, doi: 10.1108/MBE-04-2023-0052.
32. KNF. *Podmioty sektora bankowego*. Retrieved from: https://www.knf.gov.pl/podmioty/Podmioty_sektora_bankowego/Banki_w_formie_spolek_akcyjnych, 10.08.2024.
33. La Porta, R., Lopez de Silanes, F., Shleifer, A. (2002). Government ownership of banks. *Journal of Finance*, Vol. 57, No. 1, pp. 265-301. Retrieved from: <https://www.jstor.org/stable/2697840>, 14.08.2024.
34. Luszczyn, M. (Ed.) (2022). *Polska bankowość w czasie pandemii Covid-19. Wybrane zagadnienia*. Sopot: Centrum Myśli Strategicznych, p. 33.
35. Micco, A., Panizza, U. (2006). Bank ownership and lending behavior. *Economics Letters*, Vol. 93, Iss. 2, pp. 248-254, doi: 10.1016/j.econlet.2006.05.009.

36. Micco, A., Panizza, U., Yañez, M. (2007). Bank ownership and performance. Does politics matter? *Journal of Banking and Finance*, Vol. 31, Iss. 1, pp. 219-241, doi: 10.1016/j.jbankfin.2006.02.007.
37. Mierzwa, D., Jankiewicz, S. (2017). Repolonizacja sektora bankowego – poglądy i dyskusje. *Zarządzanie i Finanse Journal of Management and Finance*, Vol. 15, No. 2/2, pp. 77-88.
38. Mleczko, Ł.J. (2016). Konkurencyjność sektora bankowego a problem repolonizacji – szanse i zagrożenia. *Zeszyty Naukowe Wydziału Zamiejscowego w Chorzowie Wyższej Szkoły Bankowej w Poznaniu*, No. 18, pp. 73-88. Retrieved from: https://www.researchgate.net/profile/Adam-Baszynski-2/publication/320335773_Zmiana_tehnologiczna_jako_determinanta_struktury_konkurencyjnej_ryнку_usług_bankowych/links/5a0f50280f7e9bd1b2bdc4f6/Zmiana-tehnologiczna-jako-determinanta-struktury-konkurencyjnej-ryнку-usług-bankowych.pdf#page=73, 22.08.24.
39. *Orbis*. Retrieved from: <https://login.bvdinfo.com/R1/Orbis>, 13.10.2024.
40. Ostrowska, A. (2021). Wpływ pandemii COVID-19 na rentowność sektora bankowego w Polsce. *Zeszyty Naukowe Uniwersytetu Ekonomicznego w Krakowie*, No. 3(993), pp. 121-135, doi: 10.15678/ZNUEK.2021.0993.0307.
41. Panizza, U. (2023). State-owned commercial banks. *Journal of Economic Policy Reform*, Vol. 26, Iss. 1, pp. 44-66, doi: 10.1080/17487870.2022.2076678.
42. Panizza, U. (2024). Bank ownership around the world. *Journal of Banking and Finance*, Vol. 166, p. 107255, doi: 10.1016/j.jbankfin.2024.107255.
43. Pyka, I, Nocoń, A. (2018). Dylematy pomiaru i oceny procesu repolonizacji banków w Polsce. *Prace naukowe Uniwersytetu Ekonomicznego we Wrocławiu*, No. 531, pp. 404-418, doi: 10.15611/pn.2018.531.36.
44. Pyka, I, Pyka, J. (2017). Przesłanki i dylematy repolonizacji banków krajowych. *Zeszyty Naukowe Politechniki Śląskiej, seria: Organizacja i Zarządzanie*, No. 108, pp. 349-361, doi: 10.29119/1641-3466.2017.108.31.
45. Shen, Ch.-H., Lin, Ch-Y. (2012). Why government banks underperform: A political interference view. *Journal of Financial Intermediation*, Vol. 21, Iss. 2, pp. 181-202, doi: 10.1016/j.jfi.2011.06.003.
46. State banks on the rise (2020). In: *Transition Report 2020-21. The State Strikes Back* (pp. 68-89). London: European Bank for Reconstruction and Development.
47. Węgrzyn, P., Topczewska, A. (2023). Związek między wojną w Ukrainie a kształtowaniem się relacji depozytów do kredytów w bankach w Polsce. *Bank i Kredyt*, No. 54(2), pp. 129-152. Retrieved from: https://www.researchgate.net/profile/Pawel-Wegrzyn-3/publication/372788524_Zwiazek_miedzy_wojna_w_Ukrainie_a_kształtowaniem_sie_relacji_depozytow_do_kredytow_w_bankach_w_Polsce/links/64c8d21adb38b20d6dad3664/Zwiazek-miedzy-wojna-w-Ukrainie-a-kształtowaniem-sie-relacji-depozytow-do-kredytow-w-

bankach-w-Polsce.pdf?origin=journalDetail&_tp=eyJwYWdlIjoiam91cm5hbERldGFpbCJ9, 30.08.2024.

48. Yeyati, E.L., Micco, A., Panizza, U. (2007). A reappraisal of state-owned banks. *Economia*, Vol. 7, No. 2, pp. 209-259. Retrieved from: <https://www.jstor.org/stable/20060495>, 11.08.2024.
49. Zaleska, M. (2023). Bezpieczeństwo depozytów bankowych w Polsce w czasie wieloletniego kryzysu. *Bank i Kredyt*, No. 54(5), pp. 459-474. Retrieved from: https://bankandcredit.nbp.pl/content/2023/05/BIK_05_2023_01.pdf, 7.09.2024.

BARRIERS FOR INDUSTRY 4.0 IN EMERGING ECONOMIES – THE CASE OF POLAND

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Purpose: This study aims to identify the key barriers to implementing Industry 4.0 in emerging economies, with a particular focus on the role of human capital.

Design/methodology/approach: A literature review, industry report analysis, OECD and EUROSTAT data, industry reports.

Findings: Developing countries are expected to make extra efforts in changes in the structure of the economy to meet new challenges. The quality of human capital is of great importance here, i.e., society's demographic structure, digital skills, the structure of the economy, and enterprises' size.

Practical implications: Observation of economic reality allows sending opinions. The need is to form new skills among employees and change existing ones. Not all companies understand the opportunities and threats associated with the 4th revolution. In developing countries, this process should be supported systemically by introducing tax incentives for automation and robotization, promoting the creation of large companies, the pro-innovative transformation of the economy and creating a financial base for financing changes.

Social implications: Human capital in the emerging economies is not fully prepared for the challenges linked to the automation and robotization.

Originality/value: The article opens a discussion on macroeconomic conditions of the four industrial revolutions, mainly in the context of developing countries, and indicates potential directions of intervention and actions.

Keywords: fourth industrial revolution, unit labour cost, emerging countries, labour market, innovation, productivity.

Category of the paper: research paper.

Introduction

Human capital in emerging economies manifests a poor combination of functions to the digital economy and automation requirements. It is caused mainly by low labor cost, which paradoxically inhibits natural incentives to implement innovation. The barrier is also the primitive structure of the economy, size of entrepreneurs, lack of skilled workforce and shortage of financial resources. The dissemination of technology in human capital can have opportunities

and threats—the low level of automation results from low digital competencies. The primitive structure of the economy has contributed to the fact that in Poland, the sectoral economy is based on small enterprises and simple industries (peripheral economy). Besides, the share of agriculture and industry is still high in comparison to other EU countries. The structure of the economy is outdated and inefficient in terms of the knowledge industry. Poland and other emerging countries still lack a lot in the global race of automation and digitization. Hence they do not occupy the highest places in the global rankings.

Technical and scientific progress caused the entry to the next stage of global changes, called the fourth industrial revolution (in other words, FIR, Industry 4.0, I 4.0). The basis of these changes is information and communication technologies, the so-called ICT (information and communication technologies), which determine the speed and quality of the information provided. Due to this phenomenon's universality, ICT technologies are present in every sector, and the private sphere and increasingly cover most people. The fourth industrial revolution is not about gathering information but about processing it quickly and using it (Olender-Skorek, 2017, p. 42). Robotization and automation will undoubtedly change the face of the labor market. Thus the role of man and capital in it will change.

The fourth wave of industry's concept coincides with the assumptions of the European Union's development policy aimed at creating a solid foundation for a new economy. The implementation of industrial robots and ICT is intended to facilitate work. The final product will result from automated production lines, where people will play the role of "quality guardian" (Davies, 2015). However, the fourth revolution creates many development opportunities, provided that the country develops economic structures that absorb new solutions. Specialists believe that good preparation for new challenges requires a lot of work and human resources, which entrepreneurs are often unaware of. Even when awareness of opportunities and threats exists among the managerial staff, investment decisions are still short rather than long (Schwab, 2018, pp. 11-12).

Literature review

The fourth Industrial Revolution is not the only industry. It is driven by the increase in information and its analysis, using mobile connectivity to data transmission from different devices (Internet of Things IoT) and the automation of production (robotics). An important role plays other digital technologies, wide open as new solutions are constantly being created, e.g., 3D, cloud, etc. (Kuźniar, 2019, pp. 49-52).

The expectation of the Internet of things (IoT) is advanced Internetworking of physical devices. It is typically addressed to devices, systems and services which exist beyond machine-to-machine (M2M) communications combining different protocols, domains and applications

(Höller et al., 2014). Thanks to the interconnections of embedded devices, it is possible to implement automation in nearly all fields. An example is a smart grid or, in broader idea: a smart city. Such revolution in connections in real life of human beings is based on the Internet. First data transmission over the Internet is dated in 1969 year and was linked to two mainframe computers. Nowadays, Internet connections are available on a personal computer and many mobile devices. The milestone of computing was reached in 2010 when the total number of computers connected to the Internet has exceeded the number of people on the earth (Gershenfeld, Vasseur, 2014, p. 28).

Upcoming revolution (FIR) connected with intelligent technologies creates anxiety related to artificial intelligence (AI), flexible automation, big data, etc. The 4.0 industry is a time of advanced technology based on information and communication (Min et al., 2019).

Scientists predict technologies will change jobs around the world. It raises obvious concerns about automation processes and accompanying technological trends that cannot be fully recognized (McKinsey, 2017; Ford, 2015; Brynjolfsson, McAfee, 2014). It is currently difficult to evaluate how automation, tricks, and artificial intelligence affect the labor market and productivity. On the one hand, arguments are presented for this, artificial intelligence and robotics techniques would disown human work. On the other, many economists raised based on the analysis of technological processes translated in the final analysis not causing a decrease, but an increase in demand for work and salaries (Acemoglu, Restrepo, 2018a). It is also proved in the past that during industrial development growth process has been balanced with a share of labor in national income, which has not been significantly changed.

The research results regarding jobs under automation risk show that the tasks handled by employees are very different. Additionally, estimation depends on a used methodology. That is why they differ in the case of analyzing countries. Estimates range from a few percent (Arntz et al., 2016) to 60% (Frey, Osborne, 2013; Degryse, 2016; Manyika et al., 2017).

Think tank Technology and Innovation Foundation, in its report, calms down, based on data from 1850 to 2015, believes that historical experience proves that during the three previous industrial revolutions, the number of jobs denied was smaller than the newly created (Atkinson, Wu, 2017).

The impact of automation on tasks, productivity and work, has been studied by many economists (Acemoglu, Restrepo, 2018b; Acemoglu, Autor, 2011; Venturini, 2019), but the complete picture of consequences is still not adopted by most enterprises.

Material and methods

The aim of the article is to discuss the main economic and social barriers to the implementation of the 4th industrial revolution in emerging countries from the point of view of the use of human capital with particular regard to Poland.

The literature has been selected in this way to capture the latest reports on I.4, mainly based on the consequences of changes for human capital. The empirical analysis made use of Eurostat and OECD public statistics and industry reports. The time horizon 2000-2018 was introduced to capture the changes. However, in some indicators, the time horizons are shorter due to the lack of earlier data availability. The analysis concerns the position of Poland in comparison with the European Union and OECD countries.

Risk of automation in OECD countries and challenges for development

OECD is forecasting that risk of job automation is real but varies significantly across the countries. 14% of jobs are at high risk of automation, while 32% of jobs could be radically transformed (Fig. 1).

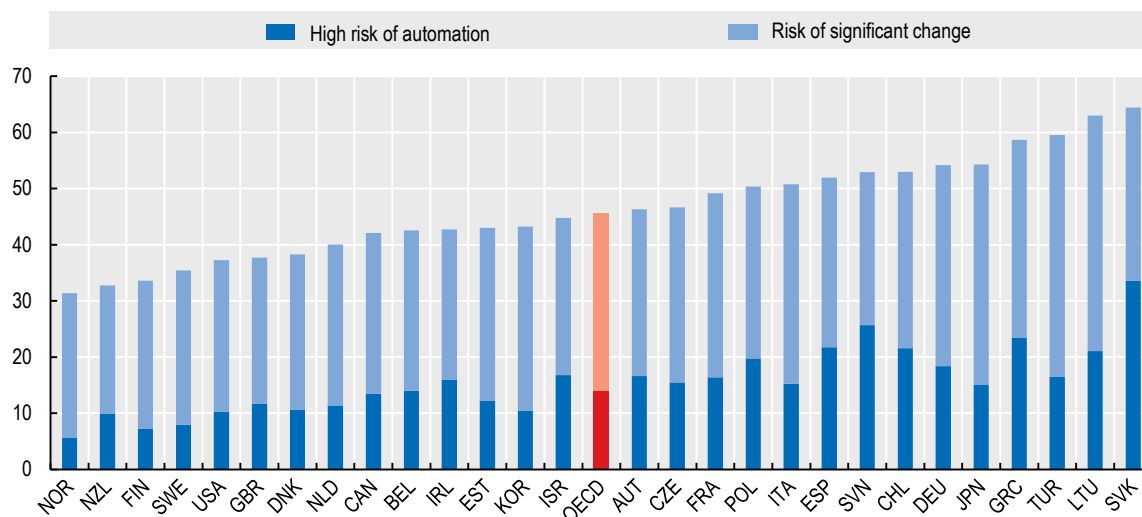


Figure 1. Jobs at risk of automation in OECD countries.

Source: OECD calculations based on the Survey of Adult Skills (PIAAC) (2012), <http://www.oecd.org/skills/piaac/>; Nedelkoska, Quintini, 2018), Automation, skills use and training, OECD Social, Employment and Migration Working Papers, No. 202, <https://doi.org/10.1787/2e2f4eeae-27%20of%20jobs%20at%20high%20risk%20from%20AI%20revolution,%20says%20OECD.%20Reuters%20OECD%20Employment%20Outlook>.

In Poland, the high risk of automation is evaluated as 20%, and it is more significant than in Western EU countries. However, these numbers only include job positions that can be eliminated but do not include the scale and number of new jobs.

According to the OECD PIAAC survey, which studies people's abilities and qualifications, over 50% of young people have very basic IT skills such as writing e-mails or web browsing or do not have such abilities (OECD, 2016). Existing education systems are often unable to reduce the differences between individual groups of employees. Better educated and paid employees have much better access to training, mobility, and self-development (OECD, 2013).

What is more – adults do not have appropriate skills for the new jobs. Six out of the ten adults lack IT skills within OECD countries or have no computer experience (Survey of adults skills-PIAAC conducted in 29 OECD countries between 2012/2015). How can we make the labor market more stable in the FIR context? OECD claims that adults should better target the disadvantaged by skill (proportion of high/low), employment status (self-employed, FT permanent) and risk of automation (high/low). For all such labor disadvantages, social protection should be adopted for non-standard workers (self-employed, part-time and platform workers), a job with 50% less possibility to become unionized and 40-50% less likely to obtain income support after losing a job (OECD 2019b).

Emerging economies face a greater predicted risk of automation in their current stage of development. A mix of employment rates should shift labor from low productivity activities (like low value-added agriculture and industries which still make up a large share of employment) to higher-productivity activities, mainly in the manufacturing and in the service sectors. The researchers related to job automation based on occupation (The World Bank, 2016), tasks (Nedelkoska, Quintini, 2018) and work activities (McKinsey Global Institute, 2017) prove a higher risk of automation in emerging economies than more advanced ones.

Although automation concerns a growing sphere of human life, it may not be economically attractive in developing countries. Costly investments in advanced technology are out of reach for most micro, small and medium-sized enterprises, which stay a significant part of emerging economies.

In addition to that, the incentive for potential automation and innovation processes is suppressed by the relative abundance of cheap unskilled labor.

The growing labor costs and falling costs of technology accelerating automation processes are an opportunity for emerging countries to get out of the middle-income trap. On the other hand, this process may be threatened by premature deindustrialization, leaving developing economies in that trap (Rodrik, 2016).

Current status of countries in race 4.0

The level of the FIR can be estimated based on several measures. To main factors taken into account in the indices belong to the level of business and public digitalization, the availability and speed of the network, the availability of highly specialized employees on the labor market and the level of education (Agencja Rozwoju Przemysłu, 2018).

One of them is the Digital Economy and Society Index (DESI), which is a weighted average of 5 areas like connectivity (weigh: 25%), human capital (25%), Internet use (15%), integration of digital technology (20%) and digital public services. The index consists of 35 co-factors and enables digital progress evaluation and comparisons within EU countries (European Commission, 2018, pp. 3-4). Other measures for FIR are:

- NRI (Networked Readiness Index), firm by World Economic Forum, examines the role of information and communication technologies (ICTs) in driving innovation.
- European Digital Progress Report (EDPR), which evaluates not only digital progress but also the state's approach to law.
- Digital Competitiveness Report made by IMD World Competitiveness Center shows the overall ranking for 63 economies covered by WCY. The rankings are calculated based on the 51 ranking criteria: 31 Hard and 20 Survey data. The methodology used in WDC ranking defines digital competitiveness into three main factors: Knowledge, Technology and Future readiness.
- ICT Development Index (IDI), public by International Telecommunications Union, evaluates access to ICT, use of ICT and ICT skills.

Poland is not at the top of the rankings list. Its results are as follows:

- in NRI (2016) - 42 out of 139 (World Economic Forum, 2016).
- DESI (2022) - 26 out of 28 (European Commission, 2022a).
- EDPR (2017) - 23 out of 28 (European Commission, 2017).
- Digital Competitiveness Report (2022) - 39 out of 63 (Bris, Cabolis, 2023).
- ICT Development Index (IDI) - 49 out of 176.

Barriers for Industry 4.0

We are far away from the top leaders, which raises the question of the restraints of FIR in Poland.

The barriers to the FIR development are:

- bureaucracy,
- lack of funds,
- high risk in relations to return,
- lack of professionals,
- lack of system support from government,
- low labor cost and high uncertainty in the labor market,
- low level of digital skills,
- rudimental - "primitive" structure of the economy,
- rapid society aging and low employment rate.

Demographics

The challenge in the case of FIR would also be the rapid pace of society aging in Poland.

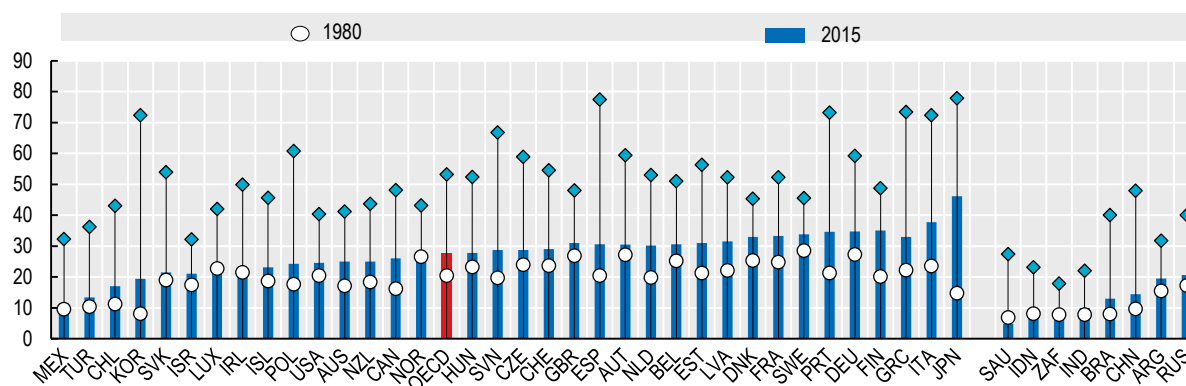


Figure 2. Projected change in the old-age dependency ratio in chosen OECD countries between 1980-2050.

Source: OECD; <http://dx.doi.org/10.1787/888933966008>.

The world's population is aging. In 1980, there were 20 persons aged 65 and over for every 100 people of working age (20-64) on average across the OECD (Fig. 2); by 2015, this ratio had risen to 28/100, and by 2050 it is projected that number will have reached 53 persons (65 old or more) for every 100 people (almost double rise between 2015 and 2050). Africa remains the youngest, while the rapid aging of the population coincides with the development of countries. The higher it is, the faster the aging process. It draws attention to the rapid aging of the population in Poland concerning the OECD. This process can be read in two ways. On the one hand, a higher standard of living, extending society's well-being, more accessible access to healthcare, and average life expectancy. In Poland, the aging process is very rapid, which increases the number of employees retiring compared to young people entering the labor market. Paradoxically, it can be a significant factor in performing a faster automation process or attracting immigration by eliminating the work shortage. Countries with the most rapidly aging populations have also been among the fastest to adopt industrial robots. However, this process is not so obvious (Acemoglu, Restrepo, 2017). Aging can be a severe problem when there is a shortage of digital skills within society required to adapt to new changes.

Structure of economy, GNP, business scale of enterprises and their impact on industry 4.0

The scale and pace of FIR implementation depend on economic fundamentals. In emerging markets, the majority of sectors are rather primitive structure-based still on agriculture and obsolete industry.

Industry 4.0 can be a profound opportunity for society, factories, households, economies if only developing countries can adapt and prepare the strategies regarding a new approach to social and economic life. One of the most challenging tasks here is to reverse developing strategies that are now in place in emerging economies. Industry 4.0 requires a significant change in the labor market, which points to low labor costs so far in such countries. Entrepreneurs do not feel any incentive to digitize and automate as they can still pay relatively not too much to their employees, which is not appropriate in the long run, as it deepens the primitive structure of the economy based on low labor cost. This could push such economies to the periphery of the world economy. There is no possibility of maintaining such a strategy with FIR as countries need to have highly specialized operations, which are linked to highly professional, well-paid employees. With FIR, we can expect increased productivity, reduced waste, promotion to the circular economy and sustainability in production and consumption (Petrillo et al., 2018).

Fig. 3 presents a share of employment in services. The transformation towards a service economy is a long-term trend already observed in the EU in the second half of the 20th century. Employment in services has slightly increased from 66% in 2000 to 74% in 2022, while in Poland 51% in 2000 to 60% in 2022.

The most significant increases in the proportion of employment in service activities since 2000 in the EU were in detail: computer programming, consultancy and information activities, real estate activities, human health activities, legal and accounting activities, security and investigation and residential care activities. The share of telecommunication has decreased when it comes to services (European Commission, 2019b).

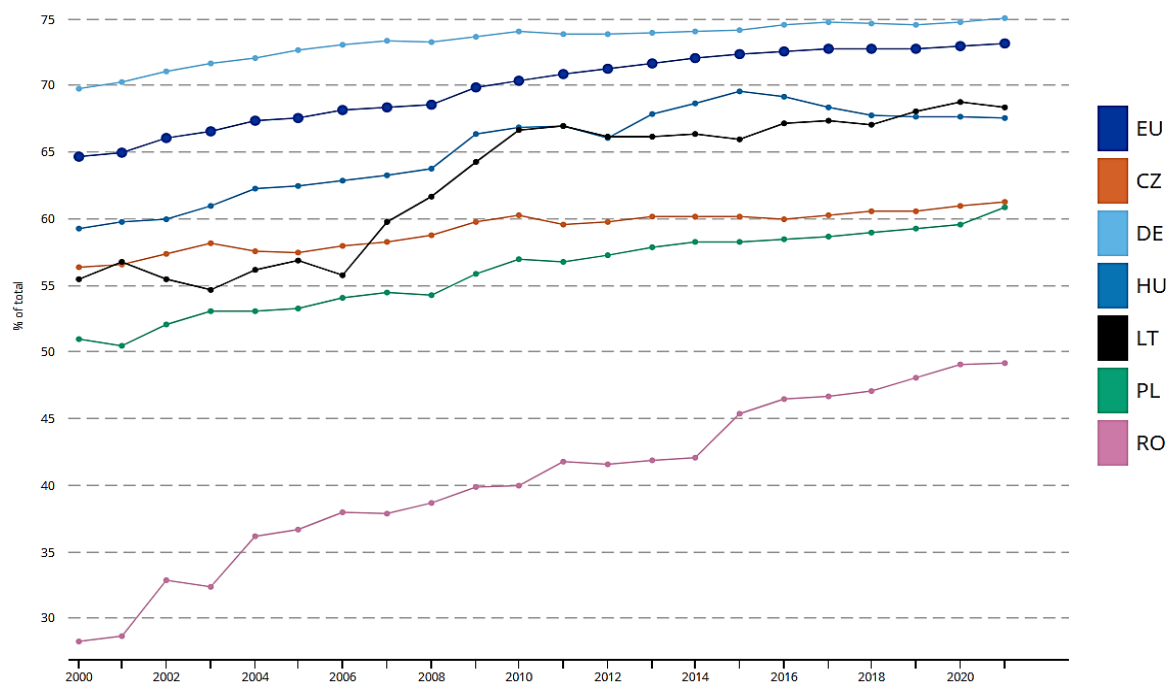


Figure 3. Share of employment in services in total employment between 2000–2022 in chosen EU countries.

Source: Eurostat, https://ec.europa.eu/eurostat/cache/digpub/european_economy/index.html?lang=en5

When it comes to employment in the industry, the trend for EU28 is diminishing (26% in 2000 and 22% in 2022 – see Fig. 4), which goes back to building a Knowledge-based economy (higher role of services).

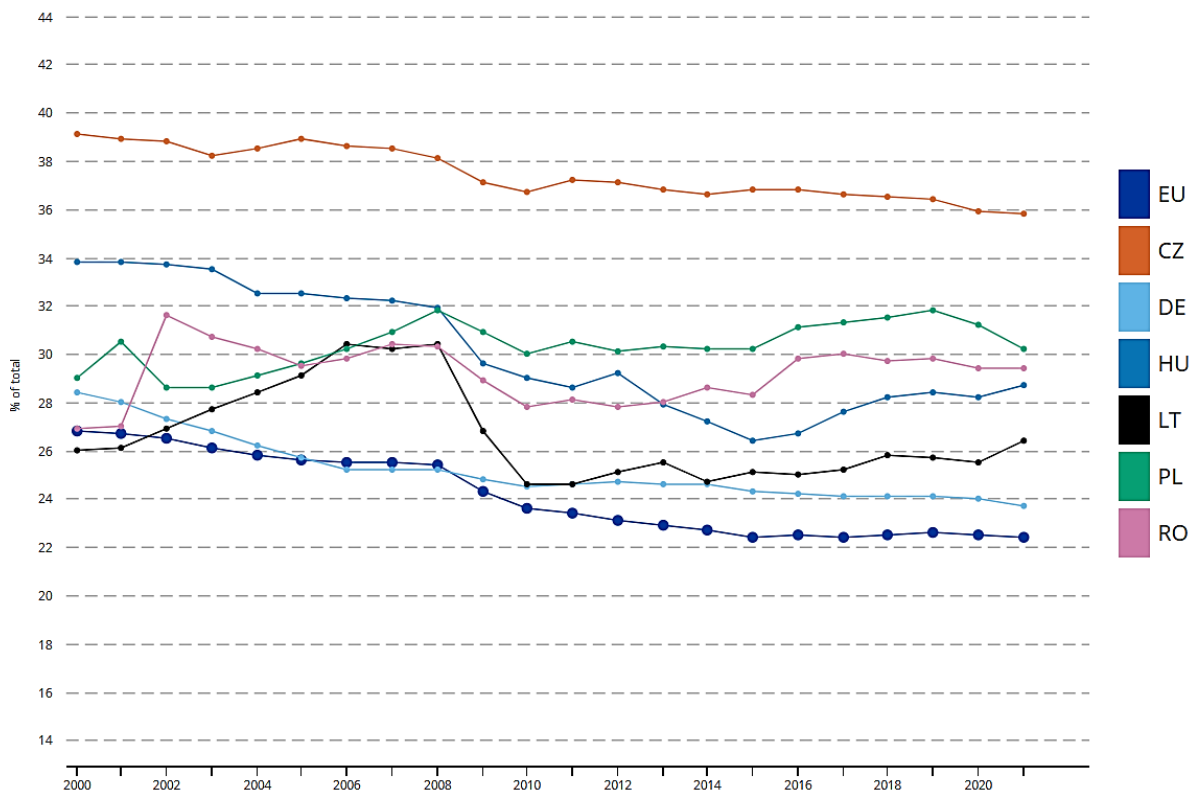


Figure 4. Share of employment in industry in total employment between 2000-2022 in chosen EU countries.

Source: Eurostat, https://ec.europa.eu/eurostat/cache/digpub/european_economy/bloc-3a.html?lang=en

Employment in agriculture in 2022 was accounted for 4% in EU, so halved from 7% in 2000 (Fig. 5). Agriculture and its productivity remain the Achilles heel of the Polish economy. The nature of this event is related to excessive defragmentation, which is rooted in the historical class division of society (Hartvigsen, 2014; Gorton et al., 2001; Bański, 2011). Employment in agriculture in Poland reached 20% in 2000 and less than 10% in 2022 what is a significant positive change. However, there is still a challenge here to increase productivity and job automation.

The highest share of agricultural employment in 2022 was in Romania (more than 20% of total employment), Bulgaria, Greece and Poland. Among the EU Member State the highest share of industrial employment was noticed in Czechia (36%), Slovakia (32%), Poland (30%), Romania and Slovenia (both around 30%), while in service activities, 80% of total employment or just over are reached by the Netherlands, the United Kingdom, Belgium, Malta, France, Luxembourg and Denmark.

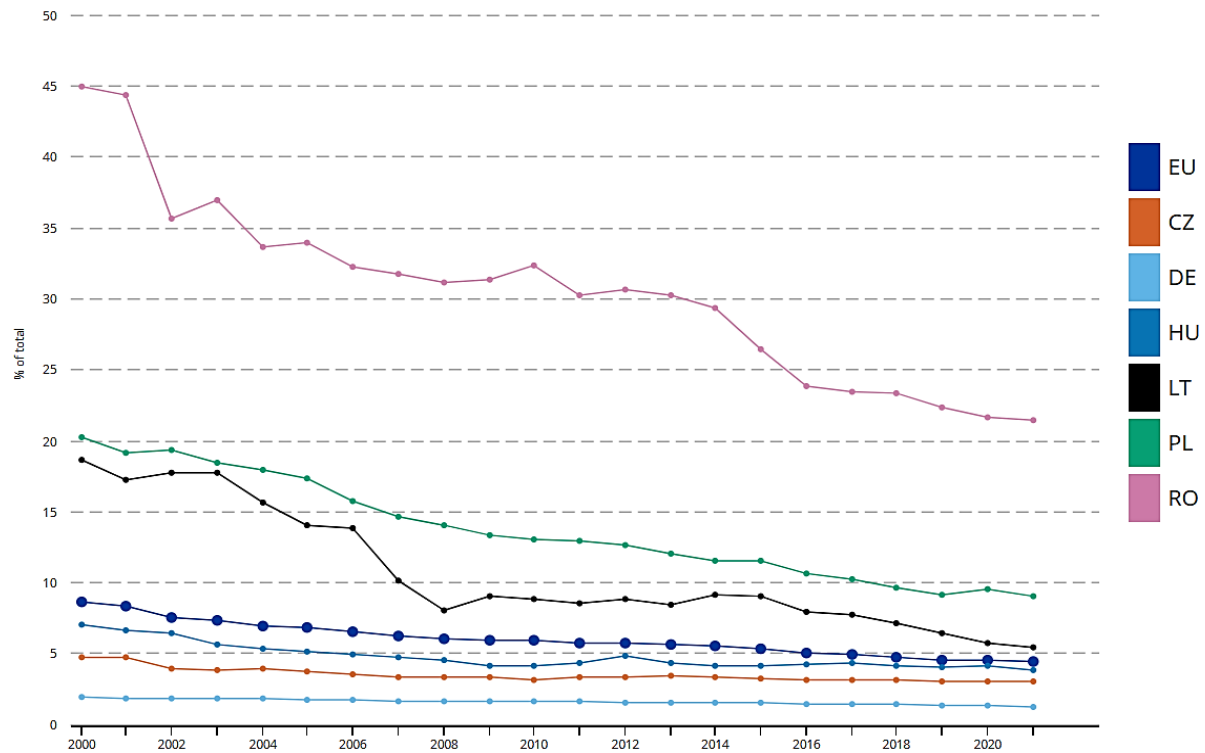


Figure 5. Share of employment in agriculture in total employment between 2000-2022 in chosen EU countries.

Source: Eurostat, https://ec.europa.eu/eurostat/cache/digpub/european_economy/bloc-3a.html?lang=en

Regarding value-added in EU, services generated 73 % of total value added in 2022, industry 22% and agriculture 5 % (Fig. 6, 7 and 8).

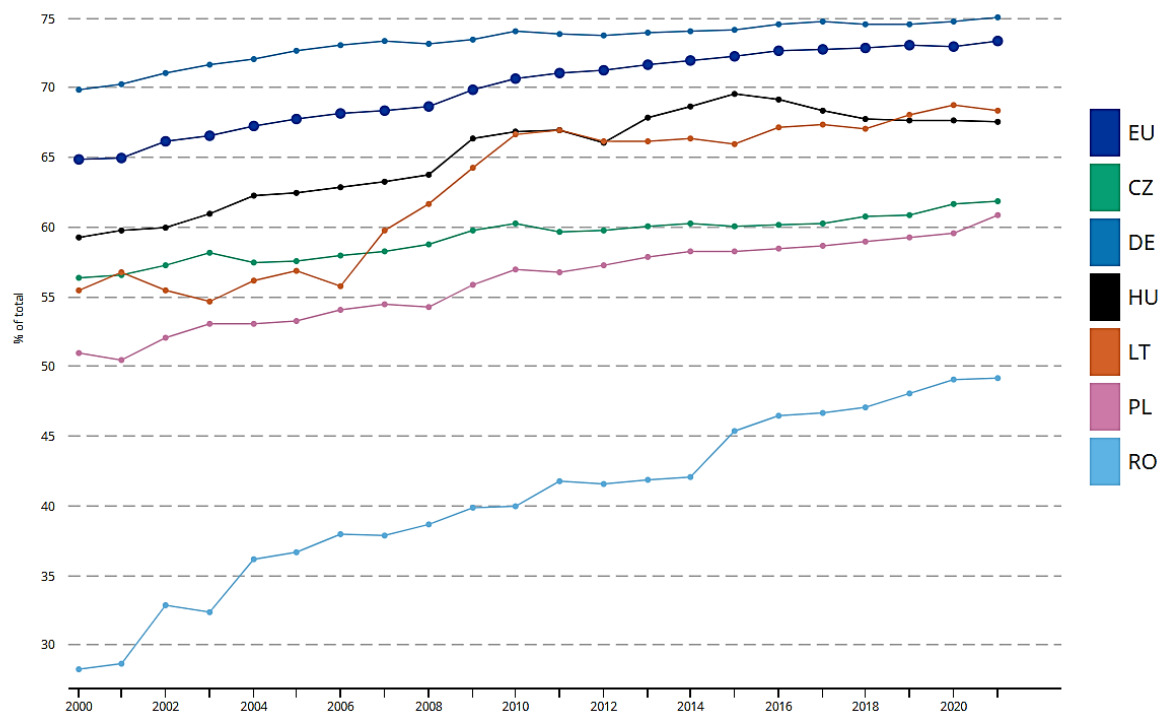


Figure 6. Gross value added by services as % of total gross value added.

Source: Eurostat, https://ec.europa.eu/eurostat/cache/digpub/european_economy/bloc-3a.html?lang=en

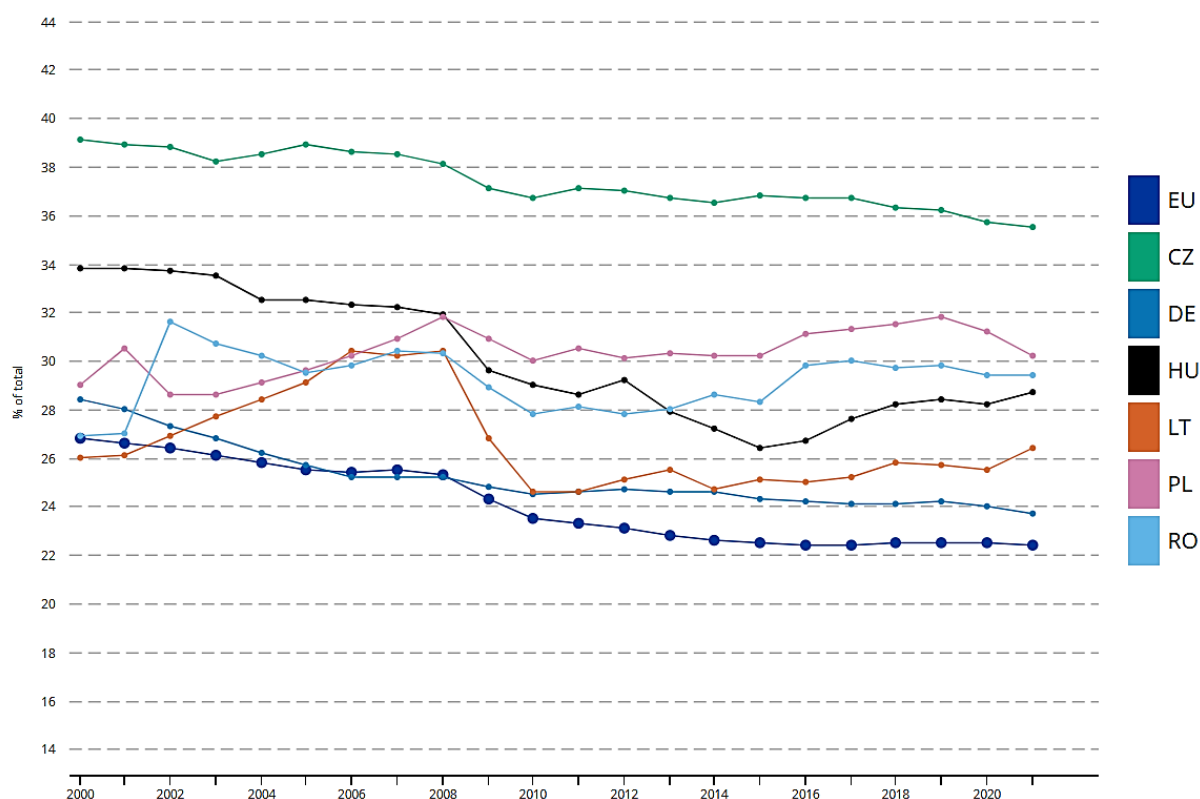


Figure 7. Gross value added by industry as % of total gross value added.

Source: Eurostat, https://ec.europa.eu/eurostat/cache/digpub/european_economy/bloc-3a.html?lang=en

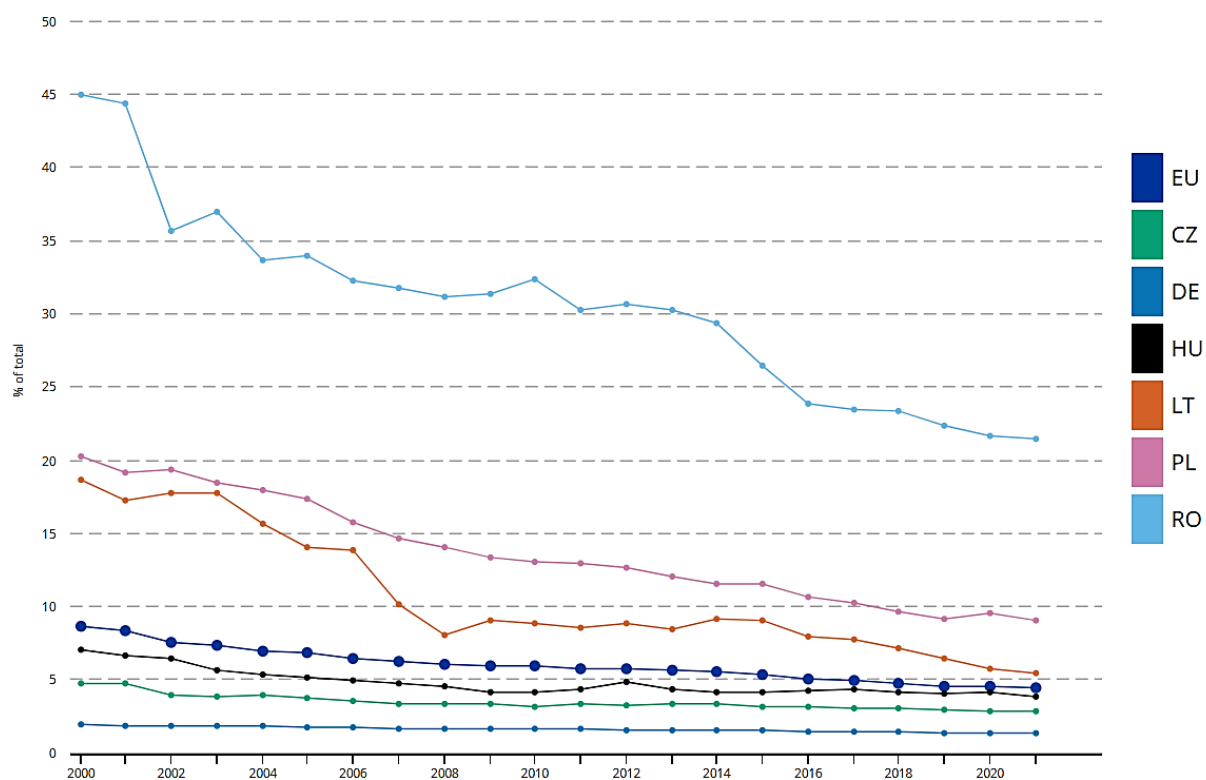


Figure 8. Gross value added by agriculture as % of total gross value added.

Source: Eurostat, https://ec.europa.eu/eurostat/cache/digpub/european_economy/bloc-3a.html?lang=en

Sectors by share in total employment and GDP are presented in Tab. 1. The main differences between Poland and the EU27 average can be seen in Agriculture, Arts, Financial activities and Construction.

Table 1.

Sectors by share in total employment and GDP in the years 2004 and 2022 for EU27 and Poland

NACE	GEO	Percentage of gross domestic		Percentage of gross domestic product	
		2004	2022	2004	2022
Agriculture, forestry and fishing	EU27	2	1,7	8,2	5,2
	Poland	3,3	2,8	17,1	9,6
Industry (except construction)	EU27	19	18,5	19,4	16,2
	Poland	22,4	22,3	24,1	24,5
Manufacturing	EU27	17,5	15,1	17,6	14,5
	Poland	16,4	17,5	20,2	21,4
Construction	EU27	5,3	5	7,8	7,5
	Poland	6,3	5,8	6,4	7,8
Wholesale and retail trade, transport, accommodation and food service activities	EU27	17,4	17,6	24,8	24,8
	Poland	22,3	21,8	22,8	23,3
Information and communication	EU27	4,3	4,8	2,4	3,4
	Poland	4,2	4,5	1,6	2,6
Financial and insurance activities	EU27	4,5	3,9	2,5	2,3
	Poland	3,4	4,7	2	2,5
Real estate activities	EU27	9	9,3	1	1,1
	Poland	5,4	4,8	1	0,9
Professional, scientific and technical activities; administrative and support service activities	EU27	8,7	10	9	12,6
	Poland	5,5	7,8	4,5	6,4
Public administration, defence, education, human health and social work activities	EU27	16,4	16,5	19,8	21,6
	Poland	13,8	3,1	17,9	19,5
Arts, entertainment and recreation; other service activities; activities of household and extra-territorial organizations and bodies	EU27	3,1	2,6	5	5,4
	Poland	1,9	1,7	2,6	3

Source: own calculations based on Eurostat data available at:

https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_10_a10_e&lang=en [nama_10_a10_e]

The most productive sectors in 2022 in Poland concerning the correlation between share in employment and GNP were Real Estate, Financial Services, Information and communication and Professional, scientific and technical activities. Agriculture offers much smaller value-added gains than those available for employment in this activity. Public administration, defense, education and both Industry and Construction will also provide a lower share of value-added than the total employed percentage (Fig. 9).

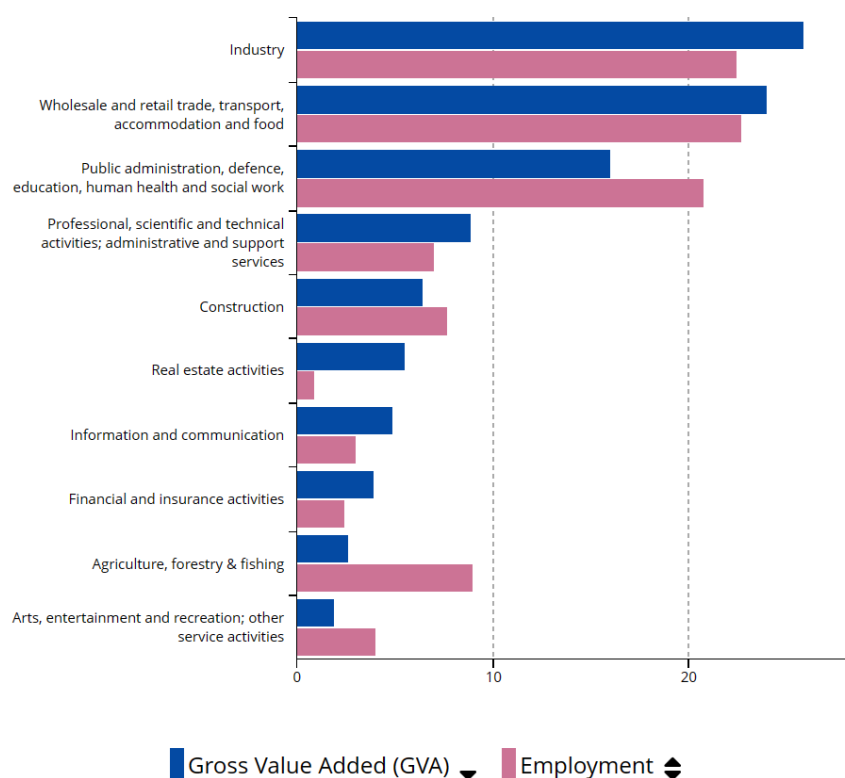


Figure 9. Gross value-added and employment by economic activity as % of the total in the 2018 year in Poland in 2022.

Source: Own calculation based on Eurostat data available at:

https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_10_a10_e&lang=en [nama_10_a10_e]

Enterprises by size and its role in FIR implementation

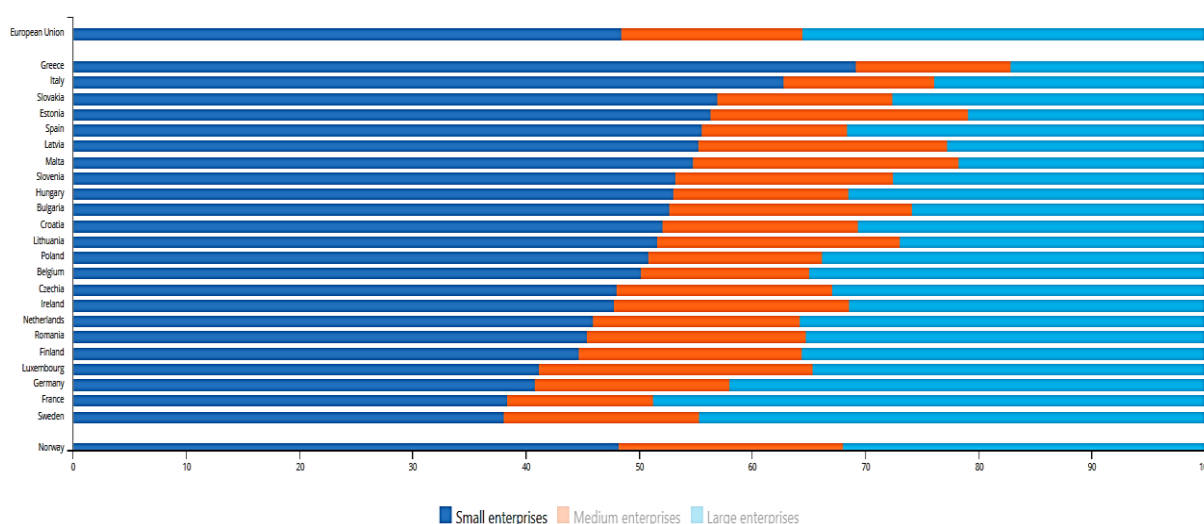


Figure 10. Number of persons employed by enterprise size class in the 2019 year in chosen EU countries (as % of total employment, total business economy).

Source: own calculation based on Eurostat: [sbs_sc_sca_r2].

Large companies in the EU account for only 0.2% of all companies. However, they generate around 35% of employment and 48% of value-added. Among EU countries, micro-enterprises most often employed in services are in Italy, Slovakia, Spain and Poland, the smallest in the Czech Republic and the Netherlands. According to the cross-section of employment for the EU average in 2019, almost half of people worked in micro and small enterprises (48,5%), 16% in medium and about one-third in large. For large enterprises, the highest proportions were found in France (49%), Sweden (45%) and Germany (42%) – see Fig. 10.

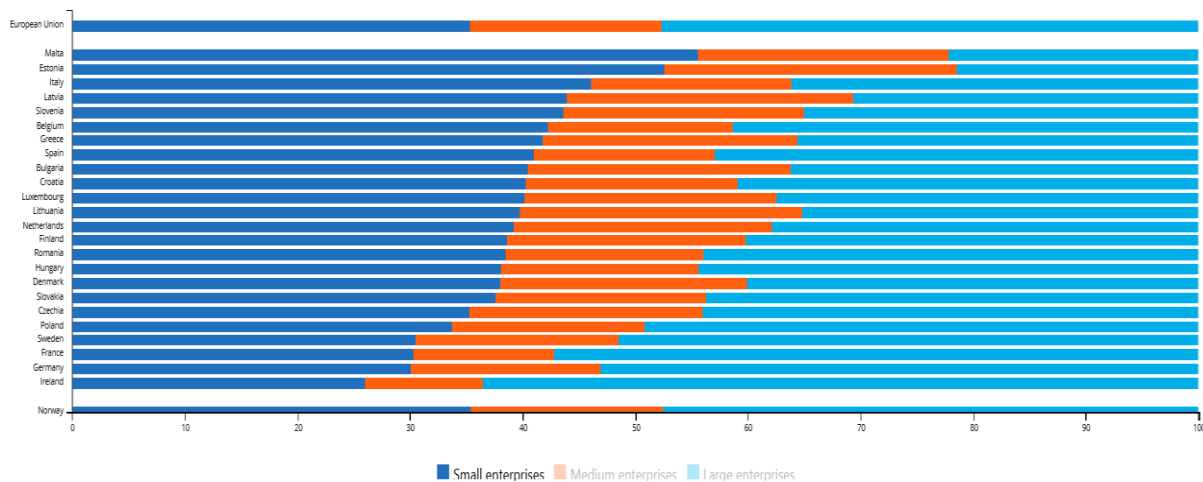


Figure 11. GNP by enterprises size in the 2019 year in chosen EU countries.

Source: own elaboration based on Eurostat: [sbs_sc_sca_r2].

The largest share in creating added value among companies in 2019 by large companies was recorded in Ireland (64%), France (57%), Germany (53%), Poland (52%) – see Fig. 11. Large companies in Poland, like in the EU, are more effective, which results from the use of economies of scale in production or the possession of adequate financial capital for development purposes. Many companies today indicate the impact of the 4th revolution on business. However, the SME sector is least prepared for technological changes and expectations (Horváth, Szabó, 2019; Smit et al., 2016). One of the main challenges is the lack of financing sources (Mittal et al., 2018). It excludes SMEs from many innovative projects. In Poland, this problem is obvious. Although the percentage of employed in micro and small enterprises is one of the highest in the EU, the share of GDP of these companies is among the lowest. Micro and small enterprises employ mainly people with the lowest qualifications, poorly secured on the labor market, often working on 'junk' or temporary employment contracts. This is related to high employment instability and lack of professional identity, defined by the term "uberization" of the labor market (Palier, 2018). In such circumstances, it is challenging to undertake long-term physical or personal investments. According to many authors, automation can hit mostly the middle class, which works in positions with medium skills, bypassing the most high-tech sectors, and people with the lowest qualifications performing non-routine manual work. This can increase income inequalities (Degryse, 2016; Graca-Gelert, 2019). Poland was one of the leading countries in the EU with the highest percentage of junk

and temporary employment contracts but in recent years has improved its position in this ranking – see Fig. 12. Netherland, Spain, Portugal, and Italy exceeded level of 15% in 2023 year. Also, in comparison with the OECD countries, Poland does not present itself and takes last places. According to the OECD, the share of employees on temporary contracts increased from 12% in 2000 to 26 in 2017 in Poland (OECD, 2019b). An improvement in the ratio was recorded between 2016 and 2017 (down from 27.4% to 26%), which may be explained by the fact that the junk contracts have been charged with social securities. The government has adopted the minimum hourly rate and improved Poland's situation in the labor market.

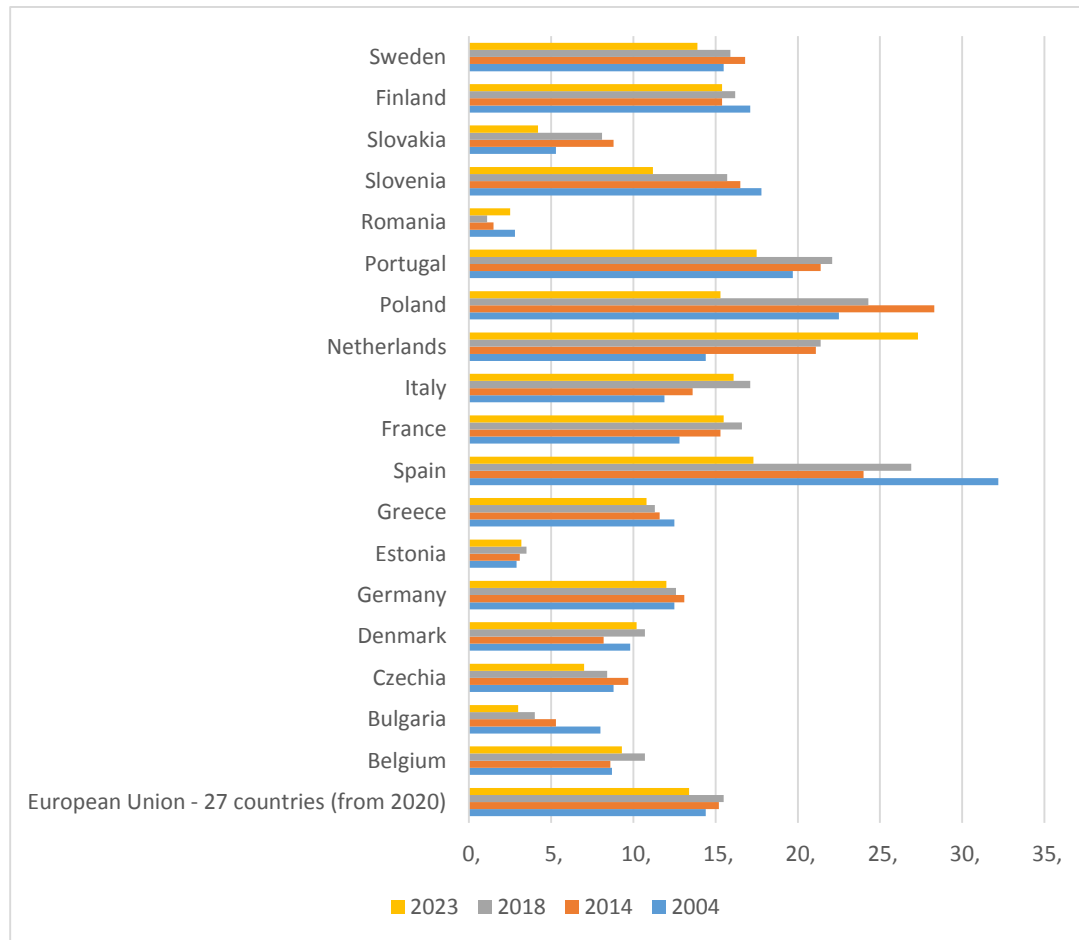


Figure 12. Temporary employees as a percentage of the total number of employees by chosen reporting EU countries between 2004-2023.

Source: own elaboration based on Eurostat [Ifsa_etpgacob].

Labor cost and productivity

As being said, low labor costs result in a slower automation rate. In relatively low-cost countries, there is less job polarization than in higher industrialized ones. Capital and labor play an essential role in determining the profitability of investing in labor-replacing technologies

(OECD, 2017). The percentage increase in labor productivity¹ in Poland over 2000-2017 was much higher than unit labor costs². On Fig. 13 it could be observed productivity in Poland has risen more than average for OECD.

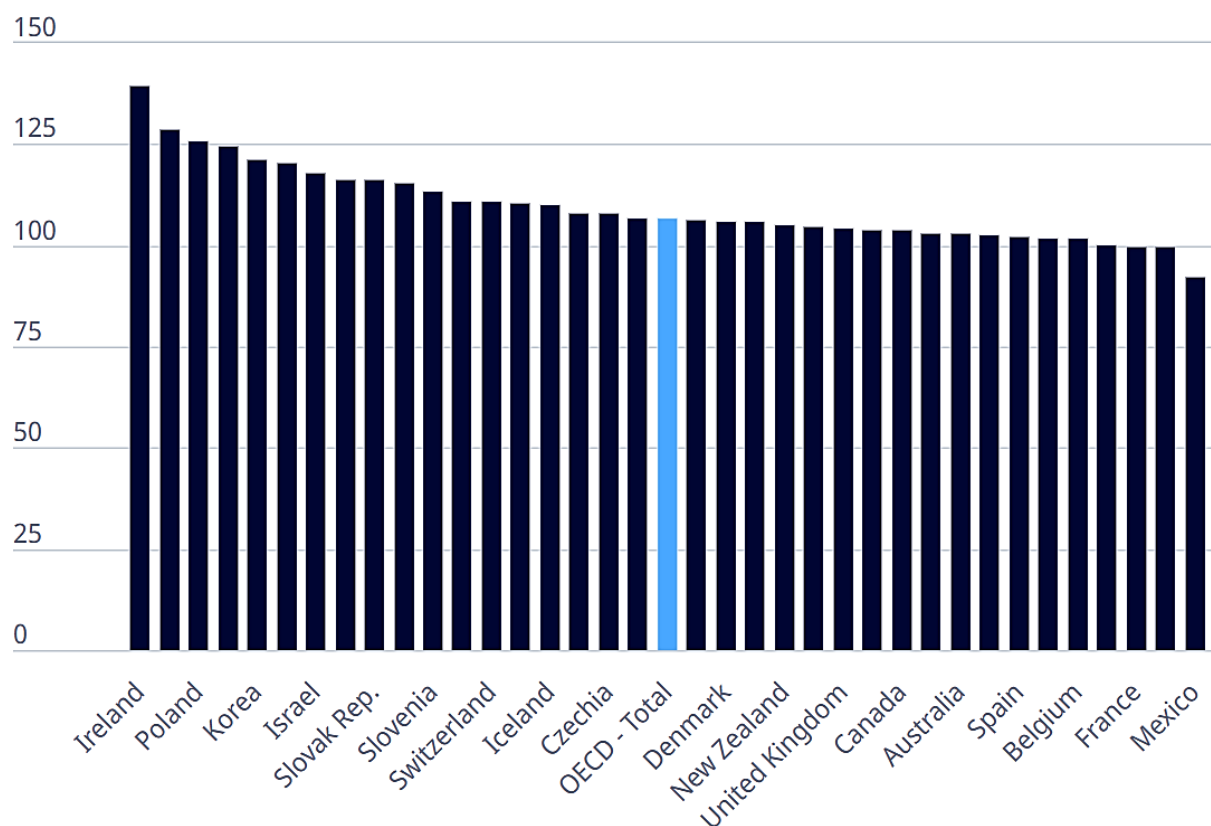


Figure 13. GDP per hour worked -Total, 2015=100, 2022.

Source: OECD (GDP per hour worked | OECD).

The analysis of hourly labor costs allows us to draw a more apparent border between the old and new EU countries – see Fig. 14. Central and Eastern Europe still provide a cheap labor base for more developed countries. This is particularly visible on the BPO (Business Process Outsourcing) market, i.e., outsourcing services in countries with low labor costs (Poland is a world leader as the location of BPO) or locating part of production (usually based on sub-components serial production). The low labor cost strategy hampers the willingness to innovate.

¹ (OECD, 2019a): Labour productivity, measured as gross domestic product (GDP) per hour worked, is one of the most commonly used measures of productivity at national level. Productivity based on the number of hours worked better reflects the utilisation of labour input than productivity based on the number of persons employed (head count).

² ULCs are defined as the average labour cost per unit of production produced. They can be expressed as the ratio of total hourly wage to hourly output (labour productivity). Total output is measured here as gross domestic product (GDP) in constant prices for the total economy and as gross value added in constant prices for the economic activity; whereas total compensation of employees is expressed in current prices.

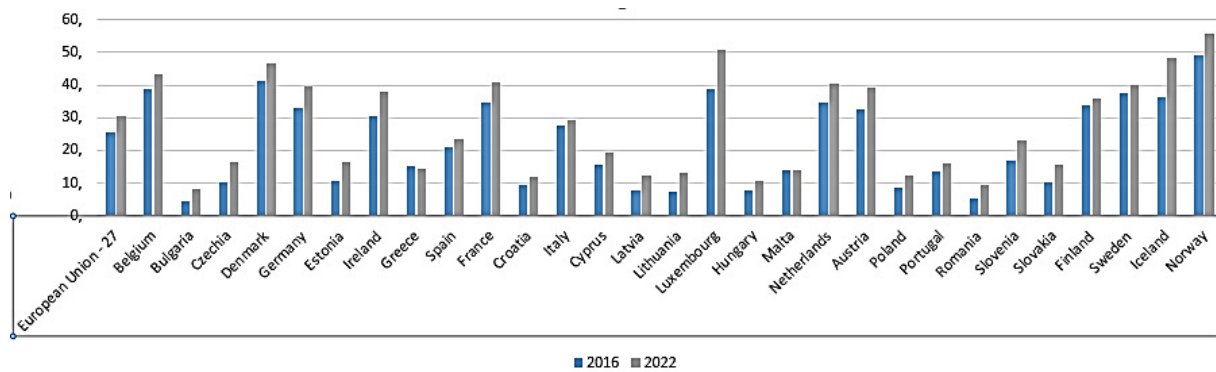


Figure 14. Hourly labor cost in Euro in chosen EU countries in 2016 and 2022 year (whole economy (excluding agriculture and public administration); in enterprises with ten or more employees).

Source: own compilation based on Eurostat (online data code: lc_lci_lev).

Conclusions

Due to Poland's low digital competencies, poor commercialization of research (low number of patents, inventions, R&D expenditures), transformations related to the fourth industrial revolution are slower. Additionally, the cost of implementing automated production lines makes the investment pay for itself within about 5-10 years. High costs of implementing new technologies, lack of large industrial plants and low labor costs cause a low level of robotization in Poland (Stolarczyk, 2017). Therefore, an increase in the minimum wage may bring about an acceleration of the automation rate. Revolutionary implementation of the concept of industry 4.0 in Poland, which requires enormous financial outlays, despite the pro-development perspective, seems impossible.

However, there is no doubt that some of the activities will be subject to cyclical robotization, which will create real economic and social challenges in human capital. Representatives of the most routine professions are threatened with professional exclusion. Hence, the need for the state's active reaction to promote lifelong learning may eliminate the harmful effects of social and economic transformations of the fourth industrial revolution.

At the higher levels of education, practical training, the matching of higher education courses with the needs of the labor market, or the practice of lifelong learning are lame. The FIR may be an impulse for exiting the trap of medium development. However, it may also deepen this distance to highly developed countries.

Recommendations on how to take advantage of the fourth industrial revolution should be read from the analysis of barriers to automation and digitization processes. Macroeconomic factors are key here. The competence mismatch will, e.g., deepen the rapid aging of the Polish society. Despite clear signals of this phenomenon, there are still no instruments that could improve the situation. Demographic changes will transform the demand line by shifting it from

the area of material goods (car, flat) to services (leisure, personal care, medical services). Automation could help sustain life quality and manage the labor market's loss resulting from people retiring quickly if other brakes were removed.

One of them is the primitive structure of the economy, with still a significant percentage of work in agriculture or industry with a simple structure (assemblies, components, not high-tech products). The transition from labor-intensive to knowledge-intensive sectors of the economy is essential in this context. Such transformation supports socio-economic development and reduces poverty in developing countries. The transition from a low-productivity, labor-intensive economy to higher productivity, capital and knowledge-intensive activities is the center of economic development. However, care must be taken that the changes do not increase income inequalities. This will continue to be the case until the competencies of the middle class in particular, which is most at risk from the FIR challenges, are strengthened.

It is crucial to address the help to today's 30 and 40-year-olds, who are sometimes referred to as the "lost generation". After introducing Poland's market economy, these are promised that they would receive high earnings after taking the trouble to complete their higher education. However, this did not happen. There is a relatively large mismatch between demand and supply in Poland's labor market. The earnings are far from those dreamt of. It is probably the reason why this generation has a high distrust of lifelong learning. The role of the state and investors is to break this deadlock. Improvement of the situation means better cooperation between science and business and the reversal of practical directions of education, support for raising adults' competencies and undertaking intangible investments connected with raising human capital.

Otherwise, the productivity of sectors will be further lower than that of highly developed countries. The reluctance to change is mainly due to low labor costs and a lack of companies' financial resources. In Poland in recent years, labor costs have been rising, but at a lower rate than productivity. Low wages and salaries of workers in Poland attract foreign capital and investments, which is positive but not necessarily in terms of the structure of investments. The businesses located are mainly BPO (Poland is the world leader in this area) or factories of large multinational corporations. However, in most cases, simple components are produced in Poland. Hence the often used term peripheral economy or assembly plant of Europe, the world. The low level of wages is to some extent caused by the class structure of Polish companies, where the vast majority of them are micro, small and medium enterprises, which are particularly struggling with the lack of funds for long-term purposes. It is reflected in the employment structure. Poland is one of the leading countries with the highest uncertainty on the labor market, read as a share of junk and temporary contracts to the total. This uncertainty does not motivate employees to improve their skills or entrepreneurs to invest. Despite the improvement of the situation resulting from the introduction of specific tools by the current government in recent years, the issue is far from ideal.

One concludes that Poland lacks large companies with a high critical mass that would accumulate significant capital and desirable investments.

FIR is the first revolution in which Poland can consciously take part. For historical reasons, we were omitted from all previous ones. Hence the great regional diversity in Poland, which hinders uniform and harmonized development.

It is essential to introduce incentives in the form of tax exemptions, guarantees. The R&D relief operating in Poland since 2016 is not addressed directly to automation and digitization processes. However, it may affect it indirectly if, under the law, the activity related to automation may constitute R&D activity. Similarly, the IP Box (the possibility of preferential taxation with a 5% tax rate on income earned by taxpayers from qualified intellectual property rights), which was introduced in January 2019, will incidentally affect the processes of robotization and automation when they create new solutions.

A solution is a one-off loss settlement in one of the following five tax years by not exceeding PLN 5 million. This solution introduced in 2019 is particularly beneficial for taxpayers whose income grows more slowly after incurring a loss. This type of investment may be precisely automation, the introduction of which requires considerable financial resources.

Despite the return that has occurred in recent years in Polish industrial policy, there is still a lack of tools addressed directly to automation. There are no tax reliefs for automation (which are used, e.g., in France, Italy, Singapore, South Korea), exemptions for automated activities (a tool used in Singapore, Thailand), favorable rules for depreciation of robots (France, Germany, USA, Singapore). The financial markets: the banking sector and the stock exchange play a significant role here in supporting projects related to the introduction of artificial intelligence and digitization. The system of financial support for small and medium-sized enterprises is not very advanced in Poland, including high-risk undertakings. Hence the need not only for systemic solutions from the state but also from financial institutions.

Acknowledgments

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References

1. Acemoglu, D., Restrepo, P. (2017). Secular Stagnation? The Effect of Aging on Economic Growth in the Age of Automation. *American Economic Review*, Vol. 107/5, pp. 174-179, <http://dx.doi.org/10.1257/aer.p20171101>
2. Acemoglu, D., Autor, D. (2011). Skills, tasks and technologies: Implications for employment and earnings. In: *Handbook of labor economics*, Vol. 4. Elsevier, pp. 1043-1171.
3. Acemoglu, D., Restrepo, P. (2018a). *Artificial intelligence, automation and work*, No. w24196. National Bureau of Economic Research.
4. Acemoglu, D., Restrepo, P. (2018b). The race between man and machine: Implications of technology for growth, factor shares, and employment. *American Economic Review*, 108(6), 1488-1542.
5. Arntz, M., Gregory, T., Zierahn, U. (2016). The risk of automation for jobs in OECD countries: a comparative analysis. *OECD Social, Employment and Migration Working Papers*, no. 189. Paris: OECD Publishing, <http://dx.doi.org/10.1787/5jlz9h56dvq7-en>.
6. Atkinson, R.D., Wu, J.J. (2017). *False alarmism: Technological disruption and the US labor market*. Information Technology & Innovation Foundation ITIF, 1850-2015.
7. Bański, J. (2011). Changes in agricultural land ownership in Poland in the period of the market economy. *Agricultural Economics*, 57(2), 93-101.
8. Bris, A., Cabolis, C. (2019). *The IMD World Digital Competitiveness Ranking 2018 results*. IMD World Competitive Center. <https://www.imd.org/wcc/world-competitiveness-center-rankings/world-digital-competitiveness-rankings-2019/>
9. Brynjolfsson, E., McAfee, A. (2014). *The second machine age: Work, progress, and prosperity in a time of brilliant technologies*. WW Norton & Company.
10. Davies, R. (2015). Industry 4.0-digitalisation for productivity and growth. European Parliamentary Research Service. *Members' Research Service PE*, 568.
11. Degryse, C. (2016). Digitalisation of the economy and its impact on labour markets. *ETUI Research Paper-Working Paper*, no. 2.
12. European Commission (2017). *Europe's Digital Progress Report*, <https://ec.europa.eu/digital-single-market/en/european-digital-progress-report>
13. European Commission (2018). *DG for Communications Networks, Content and Technology DESI 2018*. Digital Economy and Society Index. Methodological Note. Brussels.
14. European Commission (2019a). *Digital Economy and Society Index (DESI) 2019*, https://ec.europa.eu/commission/news/digital-economy-and-society-index-2019-jun-11_en
15. European Commission (2019b). *The European economy since the start of the millennium. A statistical portrait*, https://ec.europa.eu/eurostat/cache/digpub/european_economy/index.html?lang=en5

16. Ford, M. (2015). *Rise of the Robots: Technology and the Threat of a Jobless Future*. Basic Books.
17. Frey, C.B., Osborne, M. (2013). *The future of employment, Oxford Martin Programme on Technology and Employment, Working Paper*.
18. Gershenfeld, N., Vasseur, J.P. (2014). As objects go online; the promise (and pitfalls) of the Internet of things. *Foreign Aff.*, 93, 60, p. 28.
19. Gorton, M., Daniłowska, A., Jarka, S., Straszewski, S., Zawojka, A., Majewski, E. (2001). The international competitiveness of Polish agriculture. *Post-communist economies*, 13(4), 445-45.
20. Graca-Gelert, P. Income Inequality and Poverty in Poland in 2010-2017 in the Context of the Social Dimension of Industry 4.0. In A.M. Kowalski, M.A. Weresa (eds.), *Poland Competitiveness Report 2019. International Competitiveness in the context of development of Industry 4.0*. Warszawa: Szkoła Główna Handlowa.
21. Hartvigsen, M. (2014). Land reform and land fragmentation in Central and Eastern Europe. *Land use policy*, 36, 330-341.
22. Höller, J. et al. (2014). *From Machine-to-Machine to the Internet of Things: Introduction to a New Age of Intelligence*. Academic Press.
23. Horváth, D., Szabó, R.Z. (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*, 146, 119-132.
24. Kuźniar, A. (2019). The Fourth Industrial Revolution and Its impact on Global Economy. In: A.M. Kowalski, M.A. Weresa (Ed.), *Polska. Poland Competitiveness Report 2019. International Competitiveness in the context of development of Industry 4.0* (pp. 48-52). Warszawa: SGH.
25. Manyika, J., Chui, M., Miremadi, M., Bughin, J., George, K., Willmot, P., Dewhurst, M. (2017). *A future that works: Automation, employment, and productivity*. McKinsey Global Institute, McKinsey&Company.
26. McKinsey (2017). *Jobs Lost, Jobs Gained: Workforce Transition in a Time of Automation*. Report from: <https://www.mckinsey.com>.
27. McKinsey Global Institute (2017). *A future that works: Automation, employment, and productivity*, <http://www.mckinsey.com/mgi>
28. Michałowski, B., Jarzynowski, M., Pacek, P. (2018). *Szanse i wyzwania polskiego przemysłu 4.0*. Agencja Rozwoju Przemysłu. Retrieved from: https://www.arp.pl/__data/assets/pdf_file/0008/89918/_Raport_ARP_druk_po_stronie_calosc.pdf
29. Min, J., Kim, Y., Lee, S., Jang, T.W., Kim, I., Song, J. (2019). The Fourth Industrial Revolution and its Impact on Occupational Health & Safety. *Worker's Compensation and Labor Conditions. Safety and health at work*.
30. 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*, 49, 194-214.

31. Nedelkoska, L., Quintini, G. (2018). Automation, skills use and training. *OECD Social, Employment and Migration Working Papers, No. 202*. Paris: OECD Publishing, <http://dx.doi.org/10.1787/2e2f4eea-en>.
32. OECD (2013). *OECD Skills Outlook 2013: First Results from the Survey of Adult Skills*. Paris: OECD Publishing, <https://dx.doi.org/10.1787/9789264204256-en>
33. OECD (2016a). *Skills for a Digital World. Policy Brief on The Future of Work*. Paris: OECD Publishing, <https://www.oecd.org/els/emp/Skills-for-a-Digital-World.pdf>
34. OECD (2017). *OECD Employment Outlook 2017*. Paris: OECD Publishing, https://dx.doi.org/10.1787/empl_outlook-2017-en
35. OECD (2019a). *Compendium of Productivity Indicators*.
36. OECD (2019b). *Employment outlook 2019: The future of work*. OECD Publishing.
37. Olender-Skorek, M. (2017). Czwarta rewolucja przemysłowa a wybrane aspekty teorii ekonomii. *Nierówności Społeczne a Wzrost Gospodarczy*, 51(2), p. 42.
38. Palier, B. (2018). The politics of social risk and social protection in digitalised economics. In: M. Neufeind, J. O'Reilly, F. Ranft, (eds.), *Work in the digital age: challenges of the fourth industrial revolution*. Rowan & Littlefield.
39. Petrillo, A., Felice, F.D., Cioffi, R., Zomparelli, F. (2018). Fourth industrial revolution: Current practices, challenges, and opportunities. *Digital Transformation in Smart Manufacturing*, 1-20.
40. Rodrik, D. (2016b). Premature deindustrialization. *Journal of Economic Growth*, Vol. 21/1, p. 133, <http://dx.doi.org/10.1007/s10887-015-9122-3>.
41. Schwab, K. (2018). *Czwarta rewolucja przemysłowa*. Warszawa: Studio EMKA, pp. 11-12.
42. Smit, J., Kreutzer, S., Moeller, C., Carlberg, M. (2016). *Policy Department A: Economic and Scientific Policy—Industry 4.0*. European Parliament, EU, 1-94.
43. Stolarczyk, A. (2017). Kapitał ludzki—szanse i wyzwania w kontekście rozwoju koncepcji Industrie 4.0. *Nierówności społeczne a wzrost gospodarczy*, 51, 73-81.
44. The World Bank (2016). *World Development Report 2016: Digital dividends*. Washington, DC: International Bank for Reconstruction and Development, The World Bank, <http://dx.doi.org/10.1596/978-1-4648-0728-2>.
45. Venturini, F. (2019). *Intelligent technologies and productivity spillovers: Evidence from the Fourth Industrial Revolution*.
46. World Economic Forum (2016). *The global information technology report 2016. Innovating in the Digital Economy*, <http://reports.weforum.org/global-information-technology-report-2016/>

DATA INTEGRITY ANALYSIS ON THE EXAMPLE OF AIS DATABASE

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Purpose: The purpose of this paper is to address the challenges of missing data and anomalies in the Automatic Identification System (AIS) database and to explore methods for data imputation and anomaly detection to optimize maritime traffic monitoring.

Design/methodology/approach: This research applies machine learning and data imputation techniques to AIS datasets to fill gaps and detect anomalies, aiming to enhance operational efficiency in maritime transportation.

Findings: The study finds that filling missing data improves vessel traffic monitoring systems, supports better asset management, and contributes to fuel consumption optimization in maritime operations.

Research limitations: Limitations include the reliance on available AIS data quality, with future research needed to integrate real-time environmental conditions and scale the methods to large datasets.

Practical implications: The findings offer practical solutions for improving maritime operations, leading to cost savings through optimized vessel management and reduced environmental impact.

Social implications: The research supports environmental sustainability by reducing emissions in maritime transport, influencing corporate responsibility and regulatory policies.

Originality/value: his paper offers innovative methods for AIS data imputation and anomaly detection, providing value to the maritime industry by improving decision-making and operational efficiency.

Keywords: data analysis, Automatic Identification System, maritime traffic monitoring, vessel traffic monitoring systems, fuel consumption optimization.

Category of the paper: Research paper.

Introduction

Filling in data gaps alongside anomaly detection has become one of the key challenges in the field of data analysis and machine learning (Little, Rubin, 2019; Karczmarek et al., 2020a, 2020b, 2021a; Kiersztyn et al., 2020a, 2020b; Łopucki et al., 2022). Many collected datasets contain missing values, which can result from various factors such as measurement errors, technical issues, or simply lack of information. These gaps can negatively impact the quality of analysis and modeling, leading to incomplete and inappropriate results. Data gap filling plays a crucial role in the process of data analysis and interpretation (Yu, Kim, 2019). There are numerous techniques and methodologies that can be applied to address this problem, depending on the type of data, available information, and analysis objectives (Kim, 2020; Yoon, Jordon, van der Schaar, 2018; Mishra, Singh, 2021; Zhang, Guo, Liu, 2019). Filling in missing data in the AIS (Automatic Identification System) database presents a significant challenge in the field of maritime traffic monitoring and management (Abbasi, Ghanbari, Manikas, 2019; Du et al., 2021; Wang et al., 2021; Han et al., 2020). The Automatic Identification System is widely used for collecting ship information in seas and oceans. AIS data is invaluable for various sectors such as navigation safety, route planning, port management, and marine environment. However, due to various factors like equipment failures, signal interference, deliberate transponder shutdowns, and other technical obstacles, the AIS database often contains gaps and missing information (Li et al., 2019, 2020; Chen et al., 2020; Xu et al., 2019; Yang et al., 2020; Wang et al., 2019; Liu, Lu, Zhan, 2021; Jin et al., 2020; Tang, Zhu, Ma, 2019). Filling in missing data in the AIS database is essential to ensure completeness and consistency of maritime traffic information. Missing data can lead to the loss of valuable vessel location, speed, course, and other parameters, which have serious implications for monitoring and management operations. In recent years, numerous research studies and scientific works have focused on developing effective methods and techniques for filling in missing data in the AIS database. This article provides an overview of various approaches and technologies applied in this area.

Economic justification of the significance of the problem

Vessel traffic monitoring systems provide support for a wide range of applications, including asset management, safety, and pollution compliance. Access to vessel position information, including GPS data, atmospheric information, and safety regulations, can help to avoid accidents but also to optimize vessel operating costs. The use of vessel traffic monitoring systems can bring tangible benefits to owners and operators, as they enable rapid response to changes in the environment, monitoring of technical condition, as well as faster and more efficient fleet management. Through their use, it is possible to reduce operating costs and increase safety. The economic benefits associated with choosing the optimal route include reduced damage to steering and hull propulsion systems, cargo and onboard systems, lower fuel consumption, or more timely arrival at the port of destination (Jurdziński, 2010).

In the area of ship operational optimization, the reduction of operating costs is most often indicated as the main objective. A basic solution that has been used for decades is slow steaming, i.e., ship operation based on reducing speed and thus progressively reducing fuel consumption (and thus fuel costs). This is the use of a function of fuel consumption and ship speed, which is similar to a logarithmic function in its course, and thus in the upper speed ranges allows a significant reduction in fuel consumption at the expense of a relatively small reduction in speed (Cariou, 2011).

From an economic point of view, lower fuel consumption generates lower voyage costs for the ship, but also results in lower greenhouse gas (GHG) emissions into the atmosphere. An important aspect that cannot be overlooked is the reduction of bunker fuel consumption costs, as bunker fuel consumption costs typically account for 50% (Notteboom, 2006) or even more than 60% (Golias et al., 2009) of a container ship's total operating costs. These include various types of navigation systems that optimize the sea voyage taking into account navigational and market conditions (e.g., fuel management, voyage weather planning, crew eco-driving training). The process of weather optimization of a sea route involves taking into account all historical data and forecasts for a given sea body of the future sea voyage, in order to best align the route with the main objective of minimizing energy (fuel) consumption, including, in particular, consideration of wind strength and direction and wave action. The influence of sailing speed on bunker fuel consumption in the area of shipping analysis has been written about (Golias et al., 2009; Christiansen et al., 2013; Meng et al., 2014a) including considering fleet deployment (Brouer et al., 2014), or in relation to speed and displacement (Álvarez, 2009).

In practice, this refers to the avoidance of storms, strong winds, and high waves, which increase the vessel's resistance to motion and result in either a reduction in speed at the same engine rpm or the need to increase engine rpm to maintain a constant cruising speed. Methods for selecting the optimum speed were described (Mulder, Dekker, 2014). Tests carried out over

a full year on a specific vessel showed that by using a suitable weather optimization system it was possible to reduce fuel consumption by 4% over the year, with the potential to increase this reduction to 8%. An extension of this technology is to also take into account sea currents, which are quite well known and described by oceanographers. In extreme cases, this can help to increase speed by 3 kn while maintaining the same number of thruster revolutions, relative to traveling under the same conditions but without the assistance of a sea current in the direction of the voyage.

In contrast (Qi, Song, 2012), investigated the expected reduction in fuel consumption along a linear route when optimizing the voyage schedule of ships with uncertainty in port stays. (Wang, Meng, 2012) studied the problem of optimizing the sailing speed of a container ship considering container routing and handling.

The amount of fuel consumption on a ship is a function of its speed and the power required to achieve it. For each type of ship's power plant, fuel or ship size and type, this function will have different values and course. However, a common feature is that as speed increases, fuel consumption increases disproportionately faster. In other words, a unit increase in speed requires more units of fuel. While a reduction in speed has, as indicated, a non-linear effect on power demand and fuel consumption, from the point of view of shipping economics, a reduction in vessel speed has a linear correlation with capacity, where a vessel's efficiency decreases in proportion to the decrease in its operating speed. The implications of this are therefore clear and indicate that the more we reduce the speed of ships (to reduce CO₂ emissions), the less capacity they will present a global annual basis.

The potential for reducing fuel consumption by managing the ship's trim is determined to be in the range of 1-4% (ABS Ship Energy Efficiency Measures Advisory, 2013). In a study carried out under real conditions on a container ship, fuel consumption was measured alternately at trim to stern – 60 cm and trim to bow – 60 cm. It turned out that despite the increase in displacement (by 255 tons – ballast water), the demand of this ship decreased by 2.6%, so that fuel consumption dropped from 63 to 61.5 tons per day. Under optimum conditions for this vessel, the maximum reduction in power required could be 2.8 per cent, translating into a reduction in fuel consumption of 3.77 tons of HFO per day. Considering that this vessel can make an average of 4.28 voyages per year carrying 37,200 TEUs, being at sea for an average of 282 days, the fuel saving potential could be 1,063.5 tons of fuel. Under non-SECA conditions for HFO fuel, this equates to fuel cost savings of USD 382,866 per year, translating into savings of approximately USD 10.30/TEU slot per voyage. For SECA conditions and the use of MGO fuel, the savings are much higher at USD 67,650 per year, or approximately USD 15.50/TEU slot (Czermański, 2019).

Vessel traffic monitoring systems can significantly improve the efficiency and productivity of the maritime industry. Firstly, they allow real-time data to be transmitted from remote locations, allowing resources and operations at sea to be monitored and managed from anywhere in the world. Secondly, they also offer enhanced communications security, ensuring

that asset and operations data are protected from unauthorized access. Thirdly, the technology can help companies in the maritime industry optimize their operations to achieve greater efficiency and reduce operational costs, including fuel consumption. Vessel position data allows better planning of routes through specific areas. All this makes the maritime industry more efficient and productive.

Database Description

The analyzed database was purchased on a commercial basis from the S&P Global data provider, within the IHS Markit. In the whole shape, the database consists of more than 225 indicators describing a ship, where data is (or should be at least) sourced from the vessel registration authority. For the purpose of the study, there were selected 4 constant characteristics of a ship: LRIMOShipNo, MMSI, ShipName, and CallSign.

LR/IMO Ship Number is a unique digit number assigned to a ship, remaining unchanged during the whole life of the ship, even in the case of rebuilding or Ship type conversion. This IMO number is assigned to the total or greater portion of the ship's hull, including the machinery space. The IMO identification number was adopted on 19th November 1987 in IMO Resolution A.600(15). The LR/IMO Number is never reassigned to another vessel. This number is also utilized in respect of SOLAS XI 1/3 and 1/5. The consequence of that is that we can assume the uniqueness of a ship hidden behind the IMO Number whenever registered/observed.

MMSI Number (Mobile Maritime Station Identifier) is a 9-digit number assigned to a ship towards identifying her via VHF radio communications. The first 3 digits denote the country of registry; therefore, by reflagging a ship, also the MMSI number is subject to be changed and updated. The consequence of that is, it cannot be assumed the unchangeability of the number in the database.

ShipName is another changeable and variable characteristic of a ship. It should be named in English format and in accordance with the registration authority up to date. The name of a ship can be changed independently from any other events, for any reason at any time. This also has a serious impact on the data reliability, and it cannot be included as fixed data.

CallSign is an alphanumeric identifier of a ship via radio communications and, similarly to the MMSI, is related to the flag of registration. Each flag authority possesses of a call sign range from that is selected a unique number to a ship. Therefore, as well as the MMSI, it should be noted that CallSign is variable by the reflagging of a ship.

Description of missing data

The database contains a range of columns enabling the identification of the ship for which a particular entry is made in the database. The following fields are available in the database: LRIMOShipNo, MMSI, ShipName, and CallSign. In theory, we are dealing with a significant data redundancy. However, upon careful analysis of the data for the Baltic Sea basin, interesting observations can be made. It turns out that many records have missing data, with corresponding values indicating the presence of data gaps in the respective fields.

Furthermore, for the MMSI number, there are values that do not meet the conditions imposed on the MMSI number. The analysis was conducted on entries registered from 2011 to 2022. The first entry was recorded on December 31, 2011, at 23:00:20, while the last one was on June 30, 2022, at 22:59:02. The data for the year 2011 only contains information about individual entries for the last hour of that year. Therefore, to increase the clarity of the analysis, these values were added to the data for the year 2012. In total, 348,591,048 records were analyzed for the Baltic Sea. The Figure 1 illustrates the number of entries for each year.

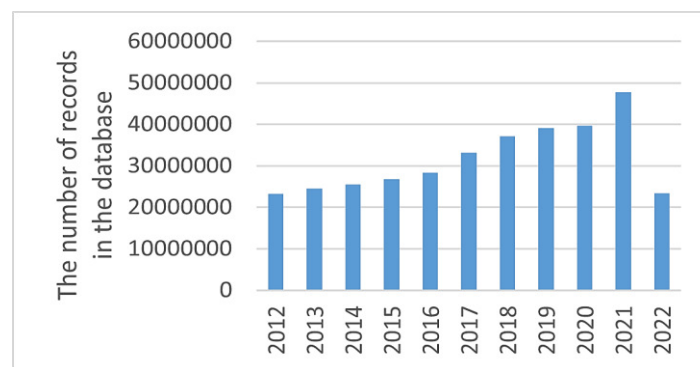


Figure 1. The number of records in the database for each year.

Table 1 presents the number of data gaps and incorrect values for each ship identification field.

Table 1.

Number of data gaps and incorrect values for ship identification fields

ID	Number of missing values
LRIMOShipNo	189607816
MMSI	537856
ShipName	2298526
CallSign	9945659

The largest number of data gaps is found in the LRIMOShipNo field. It turns out that for 189,607,816 records in this field, a value indicating a data gap was entered. Thus, the number of data gaps accounts for over 54% of all recorded entries. The distribution of data gaps across different years is also interesting.

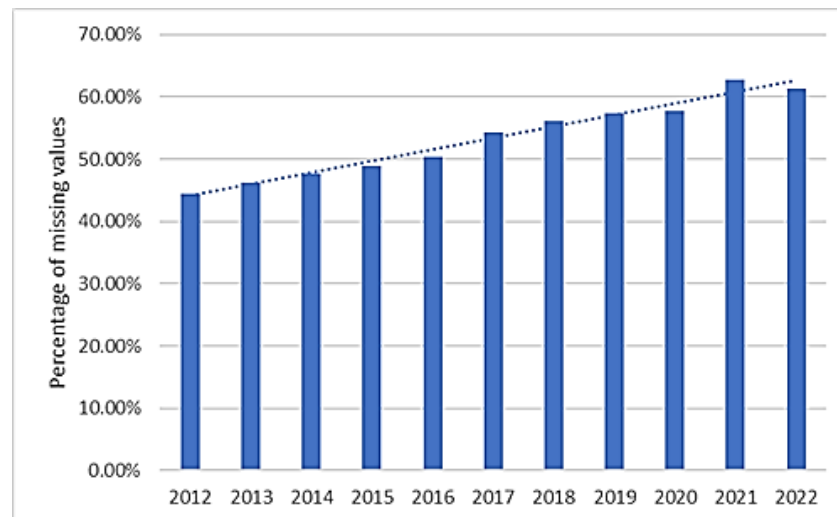


Figure 2. Percentage of data gaps for the LRIMOShipNo field.

Analyzing the results presented in Figure 2, we observe a consistent upward trend. The data for 2022 is incomplete, which may slightly distort the overall trend. In the case of other fields identifying individual records, a similar relationship is not observed (see Figure 3).

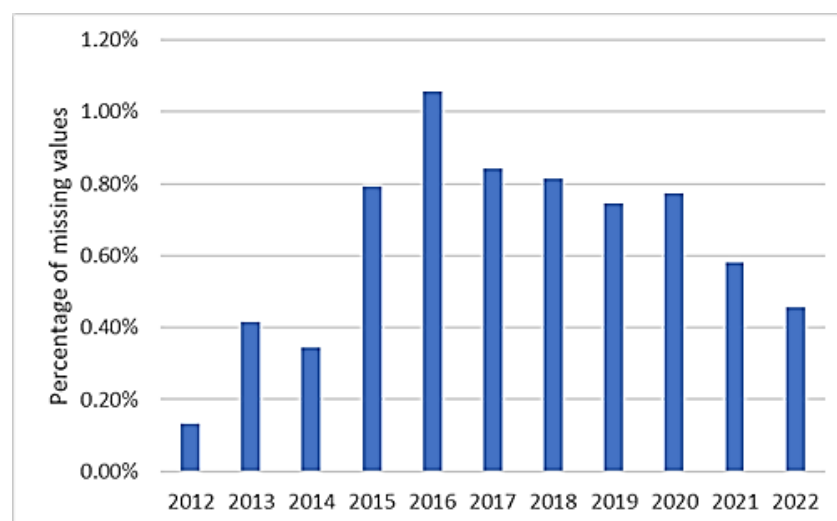


Figure 3. Percentage of data gaps for the SHIPNAME field.

At this point, a natural question arises: Is the distribution of data gaps in the LRIMO number influenced by certain factors? It seems reasonable to examine whether different months, days of the week, and hours exhibit the same level of data gaps or if there are higher percentages during certain time periods.

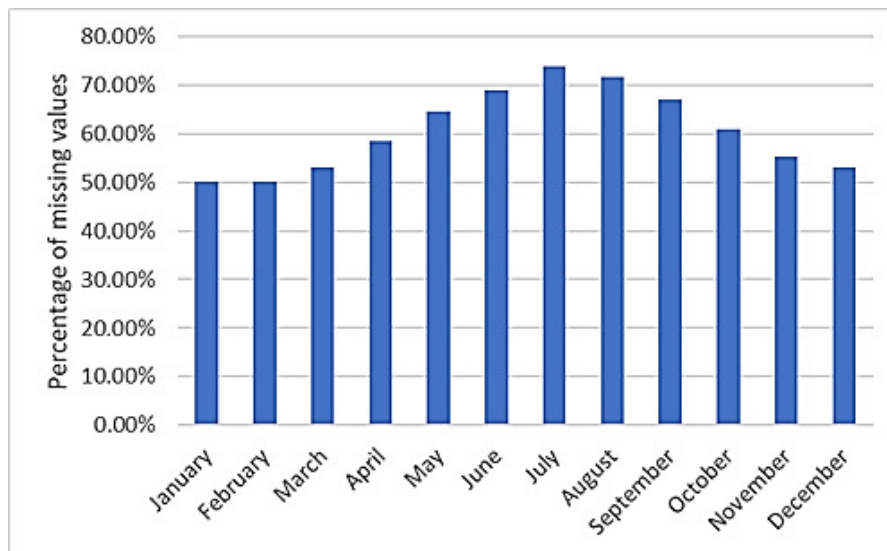


Figure 4. Percentage of data gaps in different months of 2021.

Analyzing the results presented in Figure 4, we can observe that the percentage of data gaps for the LRIMO identifier varies across different months. The highest percentage of data gaps occurs in the summer period, while the lowest is in the winter period. Furthermore, this difference is statistically significant, as confirmed by the conducted Fischer-Snedecor test. It is worthwhile to explain this fact and determine the reasons for the variation in data integrity across different months. When examining the data integrity level in terms of the influence of individual days of the week, the values obtained are presented in Figure 5.

Table 2.

Percentage of missing data for each type of vessel

ShipType	Number of occurrences	Number of gaps	Percentage of missing values
Anti Pollution	174092	88455	50.8093
Cargo	7246549	589947	8.1411
High Speed Craft	342685	160307	46.7797
Law Enforcement	470292	303333	64.4989
Medical Transport	16800	16798	99.9881
N/A	3697381	2074072	56.0957
Passenger	5021903	2887092	57.49
Pilot Boat	1441544	1260684	87.4537
Search And Rescue	1730106	1648592	95.2885
Tanker	2757768	286283	10.381
Tender	260860	251497	96.4107
Tug	2906347	900576	30.9865
Vessel	21634083	19461979	89.9598
Wing In Ground-effect	31368	27791	88.5967

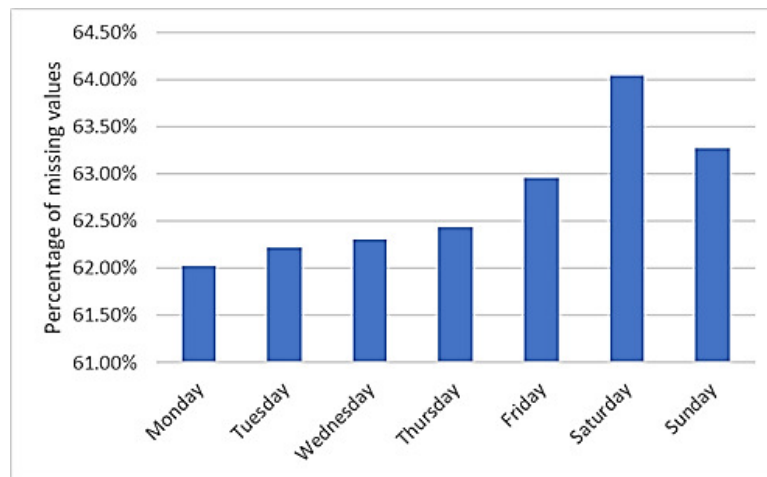


Figure 5. Percentage of data gaps on different days of the week.

In the case of the percentage of data gaps on different days of the week, we also observe a statistically significant difference. Interestingly, the highest number of data gaps is recorded on weekends, while the most consistent data comes from Mondays.

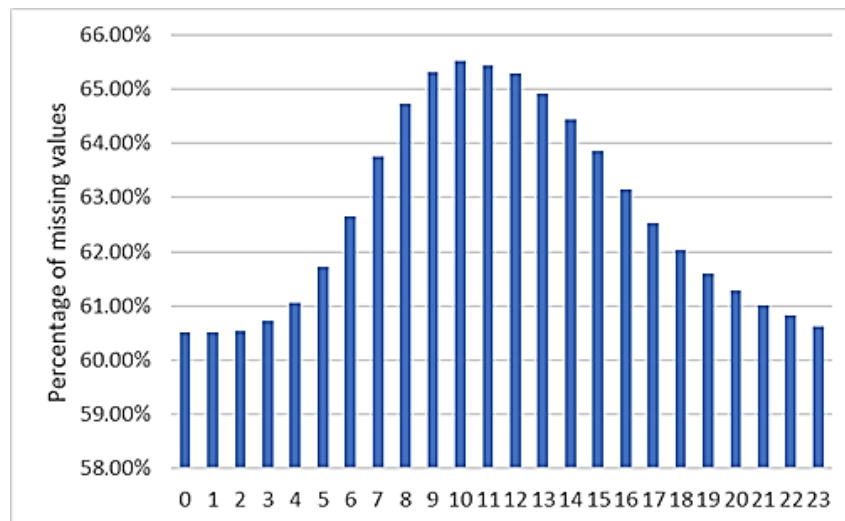


Figure 6. Percentage of data gaps broken down by hours.

Similarly to the previous analysis of the percentage of data gaps in the LRIMO column, broken down by hours (see Figure 6), statistically significant differences are observed. Additionally, it is worth noting that this distribution resembles a normal distribution, similar to the analysis based on the month of occurrence. In conclusion, it can be stated that the time of event registration statistically influences data integrity. Both the month, day of the week, and the hour of occurrence impact data quality. At this point, another natural question arises: Are there statistically significant differences for different types of ships and different ship operational statuses?

Table 3.*Percentage of gaps for each status*

MovingStatus	Number of occurrences	Number of gaps	Percentage of missing values
Anchored	9768	3365	34.4492
Aground	1297701	162617	12.5312
Constrained by draught	63120	10122	16.0361
Engaged in fishing	1695834	1369200	80.739
Moored	9968212	3020910	30.3054
N/A	20609874	20139984	97.7201
Not under command	102833	55421	53.8942
Restricted manoeuvrability	593835	214845	36.1792
Under way sailing	280263	151511	54.0603
Under way using engine	13110338	4829431	36.8368

Table 3 illustrates the impact of ship status on data quality. As expected, the highest percentage of missing data occurs in cases where the ship status is not provided. A significant percentage is also observed when the status is listed as "Engaged in fishing". Another interesting aspect is to examine how the position of the ship affects data integrity. To facilitate analysis, a random sample of 100,000 observations was taken from the data from the year 2021. The number of data gaps identifying each record was counted. In the selected sample, there were no cases where all fields were incomplete. It turns out that ships located far from the shore generally have complete data, while numerous data gaps occur for ships near the coast or inland (see Figure 7).

**Figure 7.** Percentage of data gaps broken down by hours.

The number of unique values for each identifier is different. This is evident from the values obtained for the most abundant year, 2021 (see Table 4).

Table 4.*Number of unique values for each identifier in 2021*

ID	LRIMO	MMSI	ShipName	Call Sign
Number of different values	10598	81101	39299	41161

Impact of anomalies on filling data gaps

It might seem that in cases where missing data only occurs for certain ship identifying variables, it would be easy to fill in the missing entries based on available information. However, nothing could be further from the truth. It turns out that the lack of data integrity is not limited to the occurrence of missing data but also extends to inconsistencies in the designations. For example, we will limit ourselves to one selected ship whose MMSI number is 211002010. In the analyzed database, all LRIMO field values for this ship are -1000, which of course means no data. Therefore, it is not possible to complete the LRIMO values without collecting information from additional sources. In addition, it is worth noting that there is also a lack of consistency in the ShipName and CallSign fields. The distributions of individual variables are presented in tables 5 and 6.

Table 5.*Distribution of the ShipName variable for the analyzed vessel*

ShipName	Count
-1000	1082
DELIVERANCE	3
IRMA	98
IRMA	1197
SII	4
SIRENITA	311
WINJA	1

Table 6.*Distribution of the CallSign variable for the analyzed vessel.*

CallSign	1000	DGTF	WDJ3977	XXXXX
count	936	1677	1	82

The results presented in Tables 6 and 7 confirm major problems and lack of consistency in determining such key values as variables identifying the ship. This fact confirms the belief that other data contained in the database should also be approached with a great deal of uncertainty. Table 7 presents a description of anomalies for selected variables.

Table 7.*Selected types of anomalies for individual variables*

Variable name	Anomaly description
Beam	=0
Length	=0
Speed	>90
Draught	=0
Heading	>360
Time diff	>3600
Time diff 2	<0

Values equal to zero were considered anomalies for the Beam, Length and Draft variables. In the case of the Speed variable, values greater than 90 knots were considered outliers, although it is safe to assume a much higher value. For the Heading variable, values outside the range of this variable were considered anomalies. Variables Time diff is the difference between the reporting time (MovementDateTime variable) and the time of saving to the database (ProcessedData). A delay of more than an hour was deemed to be an anomaly. In the case of the Time diff 2 variable, we are dealing with the difference between the reporting time and the expected time of arrival (ETA). If this difference is negative, i.e. the ship is late, we are dealing with an anomaly.

Analyzing the results presented in Table 8, it can be seen that in some cases the number of anomalies is significant and may affect the integrity of the data, and thus further analyses. In the case of Draft, nearly half of the records contain data that is suspected to be anomalous. In addition, it is worth noting that even in the case of a variable describing the destination port, we can encounter inconsistency. It is not uncommon for different notations for the destination port to be used, which can lead to errors.

Table 8.*The number of anomalies for individual variables and combinations of two variables*

Variable Name	Number of Anomalies	Percentage of Anomalies
Beam	2,168,148	4.54%
Length	2,102,851	4.41%
Speed	8,798	0.02%
Draught	22,03,298	46.17%
Heading	38,950	0.08%
Time Diff	633	0.00%
Time Diff 2	11,173,346	23.41%
Beam & Length	2,065,820	4.33%
Beam & Speed	7,053	0.01%
Beam & Draught	1,630,572	3.42%
Beam & Heading	5,201	0.01%
Beam & Time Diff	88	0.00%
Beam & Time Diff 2	216,140	0.45%
Length & Speed	7,053	0.01%
Length & Draught	1,573,059	3.30%
Length & Heading	5,215	0.01%
Length & Time Diff	86	0.00%
Length & Time Diff 2	208,690	0.44%

Cont. table 8.

Speed & Draught	8,664	0.02%
Speed & Heading	47	0.00%
Speed & Time Diff	3	0.00%
Speed & Time Diff 2	92	0.00%
Draught & Heading	17,184	0.04%
Draught & Time Diff	476	0.00%
Draught & Time Diff 2	378,119	0.79%
Heading & Time Diff	1	0.00%
Heading & Time Diff 2	379	0.00%
Time Diff & Time Diff 2	58	0.00%

Conclusion

The in-depth analysis of data from the AIS database carried out above confirms that the lack of data integrity is a huge problem that both scientists and specialists in the field of data analysis face on a daily basis. The comprehensive list presented above confirms that both data gaps as well as numerous anomalies and outliers are not isolated phenomena. There are numerous missing data in the analyzed database. It is true that some of them can be supplemented based on the available information, but this is not always possible. In many cases, overlapping missing values in object-identifying variables render records useless. In addition, numerous outliers and anomalies present in the database make the data analysis process more difficult. An important factor affecting the possibility of data mining is the frequent inconsistency in designations and nomenclature.

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References

1. Abbasi, A., Ghanbari, A., Manikas, I. (2019). Data imputation in marine monitoring systems using machine learning techniques. *Journal of Marine Science and Engineering*, 7(7), p. 203.
2. Álvarez, J.F. (2009). Joint routing and deployment of a fleet of container vessels. *Maritime Economics & Logistics*, 11, pp. 186-208.
3. Brouer, B.D., Alvarez, J.F., Plum, C.E.M., Pisinger, D., Sigurd, M.M. (2014). A base integer programming model and benchmark suite for liner-shipping network design. *Transportation Science*, 48(2), pp. 281-312.
4. Cariou, P. (2011). Is slow steaming a sustainable means of reducing CO2 emissions from container shipping. *Transportation Research Part D: Transport and Environment*, 16(3), pp. 263-273.
5. Chen, L., Jia, X., Yu, H., Lai, D. (2020). Missing data imputation for ship trajectories based on the combination of spline interpolation and Kalman filtering. *Advances in Mechanical Engineering*, 12(9), p. 1687814020954961.
6. Christiansen, M., Fagerholt, K., Nygreen, B., Ronen, D. (2013). Ship routing and scheduling in the new millennium. *European Journal of Operational Research*, 228(3), pp. 467-483.
7. Czernański, A. (2019). Morska żegluga kontenerowa a zrównoważony rozwój transportu. Gdańsk: Wydawnictwo Uniwersytetu Gdańskiego Instytutu Transportu i Handlu Morskiego.
8. Du, Y., He, J., Yan, S., Tang, W. (2021). Research on ship trajectory reconstruction method based on incomplete data of automatic identification system. *Journal of Navigation*, 74(1), pp. 55-70.
9. Golias, M.M., Saharidis, G.K., Boile, M., Theofanis, S., Ierapetritou, M.G. (2009). The berth allocation problem: Optimizing vessel arrival time. *Maritime Economics & Logistics*, 11, pp. 358-377.
10. Han, S., Li, C., Yang, C., Ding, M. (2020). A novel method for filling incomplete AIS data based on extended Kalman filtering. *IEEE Access*, 8, pp. 138190-138199.
11. Jin, L., Zhao, J., Zhang, Y., Zong, C. (2020). Missing data imputation for ship trajectories using long short-term memory neural network. *Applied Sciences*, 10(13), p. 4504.
12. Jurdziński, M. (2010). Metody zmniejszenia zużycia paliwa w procesie eksploatacji statku. *Zeszyty Naukowe Akademii Morskiej w Gdyni*, 67, pp. 18-28.
13. Karczmarek, P., Kiersztyn, A., Pedrycz, W. (2020). *Fuzzy set-based isolation forest*. 2020 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE), July 2020, pp. 1-6.
14. Karczmarek, P., Kiersztyn, A., Pedrycz, W., Al, E. (2020). K-Means-based isolation forest. *Knowledge-based systems*, 195, p. 105659.

15. Karczmarek, P., Kiersztyn, A., Pedrycz, W., Czerwiński, D. (2021). Fuzzy c-means-based isolation forest. *Applied Soft Computing*, 106, p. 107354.
16. Kiersztyn, A., Karczmarek, P., Kiersztyn, K., Pedrycz, W. (2020). Detection and classification of anomalies in large datasets on the basis of information granules. *IEEE Transactions on Fuzzy Systems*, 30(8), pp. 2850-2860.
17. Kiersztyn, A., Karczmarek, P., Łopucki, R., Pedrycz, W., Al, E., Kitowski, I., Zbyryt, A. (2020). *Data imputation in related time series using fuzzy set-based techniques*. 2020 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE), July 2020, pp. 1-8.
18. Kim, J. (2020). Missing not at random imputation with recurrent neural networks. *Journal of the American Statistical Association*, 115(530), pp. 461-476.
19. Li, A., Ma, X., Li, G., Zhang, X. (2020). AIS data imputation method based on convolutional LSTM network. *IEEE Access*, 9, pp. 1372-1382.
20. Li, Y., Zhang, Z., Hu, Y., Sun, Y. (2019). Research on method of ship trajectory data interpolation based on AIS data. *Mathematical Problems in Engineering*, p. 2562451.
21. Little, R.J.A., Rubin, D.B. (2019). *Statistical analysis with missing data*. John Wiley & Sons.
22. Liu, M., Lu, Y., Zhan, J. (2021). A ship trajectory prediction method based on LSTM neural network using AIS data. *IEEE Access*, 9, pp. 3508-3522.
23. Meng, Q., Wang, S., Andersson, H., Thun, K. (2014). Containership routing and scheduling in liner shipping: Overview and future research directions. *Transportation Science*, 48(2), pp. 265-280.
24. Mulder, J., Dekker, R. (2014). Methods for strategic liner shipping network design. *European Journal of Operational Research*, 235, pp. 367-378.
25. Notteboom, T.E. (2006). The time factor in liner shipping services. *Maritime Economics and Logistics*, 8(1), pp. 19-39.
26. Qi, X., Song, D.-P. (2012). Minimizing fuel emissions by optimizing vessel schedules in liner shipping with uncertain port times. *Transportation Research Part E*, 48(4), pp. 863-880.
27. Tang, Y., Zhu, T., Ma, F. (2019). Trajectory reconstruction of incomplete AIS data based on improved particle filter algorithm. *Mathematical Problems in Engineering*, p. 4932180.
28. Wang, A., Meng, Q., Du, Y. (2015). Liner container seasonal shipping revenue management. *Transportation Research Part B*, 82, pp. 144-160.
29. Wang, A., Ye, X., Tsui, K.L. (2017). *Time series imputation with generative adversarial nets*. Proceedings of the 23rd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, pp. 755-764.
30. Wang, A., Zhou, J., Zhang, X., Li, Y. (2021). Trajectory-based ship movement prediction using AIS data and random forest. *Journal of Navigation*, 74(3), pp. 615-632.
31. Wang, S., Meng, Q. (2012). Sailing speed optimization for container ships in a liner shipping network. *Transportation Research Part E*, 48(3), pp. 701-714.

32. Wang, S., Thun, K. (2012). Minimizing CO2 emissions by optimizing the vessel speed and fleet operation in container shipping. *Transportation Research Part E*, 48(5), pp. 879-890.
33. Xu, Y., Cheng, J., Zhang, Y., Liu, X. (2019). Missing data imputation for AIS based on matrix completion and belief propagation. *Complexity*, p. 6212681.
34. Yang, B., Yang, C., Wang, Y., Zhao, C. (2020). A data recovery algorithm for incomplete AIS data based on multisource fusion. *Mathematical Problems in Engineering*, p. 8839494.
35. Yang, L., Zhang, J., Wang, W. (2020). A novel method for data reconstruction of AIS based on trajectory clustering. *IEEE Access*, 8, pp. 146084-146095.
36. Yoon, J., van der Schaar, M. (2020). Missing data imputation with GANs: Theory and applications. *Journal of Machine Learning Research*, 21, p. 1362.
37. Yoon, J., Jordon, J., van der Schaar, M. (2018). *GAIN: Missing data imputation using generative adversarial nets*. International Conference on Machine Learning, pp. 5672-5681.
38. Yu, H., Kim, J. (2019). Interpretable missing not at random models for decision making with missing data. *Journal of Machine Learning Research*, 20(17), pp. 1-32.
39. Zhang, Y., Guo, S., Liu, Y. (2019). A review on missing data imputation methods for environmental sensor networks. *Computers, Environment and Urban Systems*, 77, p. 101364.
40. Zhang, Y., Hu, S., Li, Y. (2020). Missing value imputation based on deep learning and fuzzy systems. *IEEE Transactions on Fuzzy Systems*, 28(10), pp. 2341-2350.
41. Zhao, J., Li, X., Wang, S. (2020). AIS data imputation based on LSTM and KNN. *Mathematics*, 8(12), p. 2150.

FINANCIAL ASPECTS OF INNOVATION ACTIVITY OF ENTERPRISES

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Purpose: The purpose of the paper is to assess the innovative activity of enterprises in Poland with a particular focus on the sources of funding of projects implemented by industrial and service enterprises, as well as to examine the relationship between the respective forms of funding and the level of innovative activity of small, medium and large business units.

Design/methodology/approach: The first part of the article includes a critical analysis of the literature on the financial determinants of the innovative activity of business units. The empirical analysis was based on statistics published by the Central Statistical Office of Poland (CSO), which were used to assess the level and structure and dynamic of the respective sources of funding for innovative activities of enterprises in Poland in 2013-2022. The Pearson correlation coefficient was used for examining the relationship between the scale of innovative activity of enterprises and the sources of their funding.

Findings: The primary source of funding for the innovative activities of enterprises in Poland was their own funds, the level of which had the greatest impact on undertaking activity in this area. In SMEs, especially small enterprises, funds obtained from abroad were also important, and the shortage of own financial resources necessary to cover expenses later reimbursed by EU grants was supplemented by bank loans, access to which made it possible to increase the scale of ongoing projects. Large companies with financial credibility and assets to secure loan repayment, made their innovation activity highly dependent on the ability to raise capital from financial institutions, and in addition they were willing to use alternative forms of funding.

Originality/value: The analysis includes not only the scale and sources of funding of innovative activity of enterprises in Poland, but also the relationship between the level of expenditure on innovations and the use of various forms of funding.

Keywords: innovations, innovative activity, sources of financing.

Category of the paper: Research paper.

1. Introduction

Constant changes in the environment, as well as increasing competition, force companies to constantly develop, a key element of which is innovation. In modern economy, innovation, encompassing a set of organized activities indispensable for the growth of a company's

efficiency and competitive position, is seen as a tool and also a function of entrepreneurship, whose task is to transform an idea into a specific product or service that meets specific needs, with the ability to generate profit, multiply capital and create the conditions for the continued operation and development of the enterprise (Duraj, Papiernik-Wojdera, 2010). Investing in novelties, accompanied by an increased demand for capital and a higher level of risk, is one of the most important challenges currently facing companies aware that modern solutions enable them to improve and consolidate their market position. The implementation of projects that usually exceed the financial capabilities of enterprises, with insufficient levels of own financial resources, prompts business units to seek funds from other sources, the most important of which are funding from financial institutions, as well as public support from the EU and national budgets.

The purpose of the article, having first introduced the essence of innovation funding, is to assess the innovative activity of enterprises in Poland in 2013-2022 on the basis of data from the Central Statistical Office of Poland taking into account innovation expenditures and sources of funding innovative activity of industrial and service enterprises in the adopted studied period, as well as to examine the relationship between the level of innovation expenditures in SME entities and large enterprises and the respective sources of their funding.

2. Sources of Financing for Innovative Activities

Innovation activity, which is the process of transforming existing capabilities into new ideas and putting them into practice, is associated with large expenditures, long payback periods and specific risks (Makiela, 2013; Fagerberg, 2005). One of the main factors influencing innovation decisions, allowing further development and faster adaptation to the constant changes in the environment, is the opportunities for funding innovative solutions. Financial determinants of innovation can be either external or internal. The former are independent of the policies and financial decisions of economic managers, and their nature and impact are closely related to the development of the economy and the financial system operating within it. The latter depend primarily on the entity's financial policy and market strategy, the implementation of which affects the financial structure. In order to optimally select a funding structure, it is necessary to determine current and future funding needs, taking into account the availability of a given source, as well as its price. Maintaining the right capital structure is very important, as it allows the company to maintain its credibility and promotes the provision of resources for further funding, thus reducing the risk of not having sources of capital for innovative ventures (Krawczyk, 2012; Bal-Woźniak, 2020).

Business owners who intend to pursue innovative ventures face many dilemmas that can effectively constrain them. Among the most important factors inhibiting the implementation of innovations by companies are undoubtedly the sources of funding, the cost of the innovation process and economic risks (Chen, Hai, Wu, 2015; Santos, Cincer, Cerulii, 2024). The high risk of not achieving the expected results of innovation implementation, which increases the cost of raising funds, is an important reason for not undertaking innovative activities (Crowley, 2004).

In terms of analysis of factors shaping the structure of funding, it is important that companies prefer equity in funding, including in funding innovative activities (Brojakowska-Trzaska, 2018; Pia, Lin, 2020). Own financial resources that are often inadequate mean that implementation of innovative projects that enable the enterprise to develop and increase its value requires external capital. Therefore, the concept of funding innovative activities makes it reasonable to adopt the so-called financial engineering, i.e. funds from various sources (Janasz, Kaczmarek, Wasilczuk, 2020). Equity can be raised both from internal sources, i.e. from a portion of the organization's net profit, and from external sources, among others from the proceeds from increasing shares and issuing stocks. In turn, external capital is the means by which funds are provided to enterprises from various institutions operating in their environment (Janiszewski, 2022). However, the ability to raise the necessary capital depends on the scope of business, the period of operation and the development phase of the enterprise, the form of ownership, the quality of the management team in place, the situation in the external environment, but most importantly - the venture being implemented. The financial needs of the companies that implement innovations are also subject to changes, which, among others, are due to the costs related to development of a new product or service, the state of technical sophistication of the innovation project and its degree of risk, or the phase of the innovation process to which the funding relates (Kokot-Stępień, 2018; Szatkowski, 2016; Zakrzewska, Kijek, 2017).

Innovative activities can be financed from the company's equity resources, as well as from market sources and public funds. However, companies face significant difficulties in funding innovation from external sources. Obtaining public support is hampered by a complicated procedure, excessive formalization and bureaucracy, a large number of normative acts and their frequent changes, as well as insufficient cooperation between science and business. Complicated procedures for granting subsidies, often unclear criteria for examining applications, as well as the way in which subsidies are granted (advance payments or reimbursement of costs incurred) are a significant barrier to obtaining national and EU subsidies. In turn, banks, fearing excessive risk, often take a dim view of funding risky innovative ventures. Among the impediments to accessing bank loans are lack of credit history, lack of the required collateral, interest rates and complicated banking procedures (Lewandowska, 2018; Janasz, 2020).

The improvement in availability of debt capital for innovative activities of enterprises should translate into their development and increase in incomes. It is important to start activities that allow for the implementation of innovative products and financial services which stimulate the increase in opportunities for financing with outside capital (Krawczyk-Sokołowska, Łukomska-Szarek, 2017).

3. Innovation Activity of Businesses in Poland

In Polish enterprises, the level of outlays on innovation is still relatively low, but what is satisfactory is the fact that in the years covered by the analysis, the value of outlays on innovation steadily increased from nearly 33 to over 55.7 billion zlotys. Thus, taking into account the border years of the research period, their level increased quite significantly, by nearly 22.7 billion zlotys, or 69%.

Based on data from the Central Statistical Office, Figure 1 illustrates the financial outlays incurred in 2013-2022 for the innovative activity of enterprises in Poland. In addition, the structure of individual sources of financing for this activity was assessed, as shown in Figure 2.

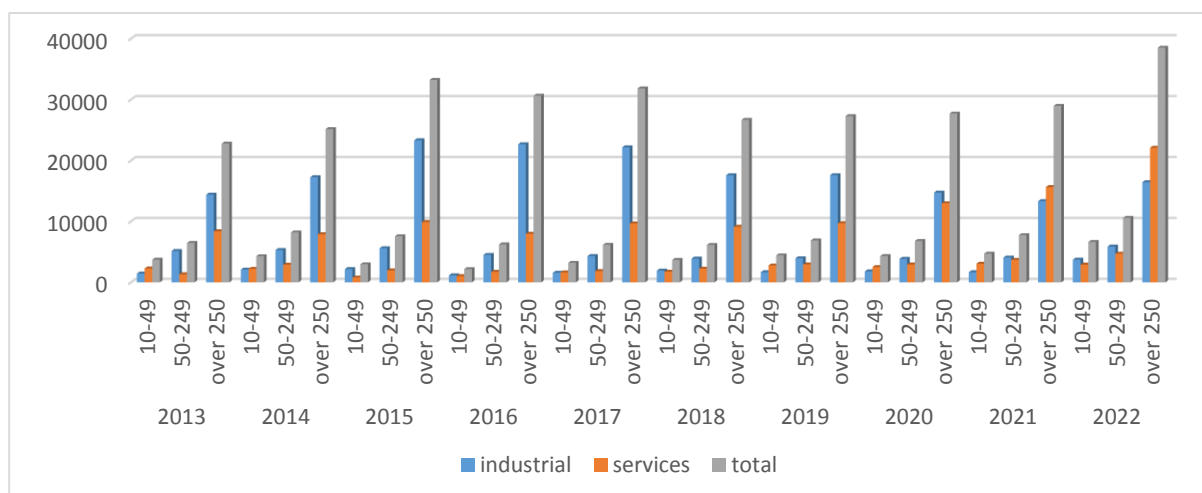


Figure 1. Expenditures on innovation activity of enterprises in Poland in 2013-2022.

Source: Own elaboration based on the data of the Central Statistical Office of Poland (CSO).

The largest impact on this value came from ventures implemented by companies in the services sector, where spending on innovation increased by more than PLN 17 billion. In terms of the size of their operations, expenditures increased to the greatest extent in large businesses (an increase of more than PLN 15.7 billion), while in small businesses the increase in expenditures of more than PLN 2.9 billion meant an increase of 78% in the years 2013-2022. In turn, taking into account the sector and size of business entities, the largest growth was recorded in medium-sized service companies, where expenditures increased 3.5 times in 2013-

2022. What is noteworthy is the fact of poor cooperation between enterprises and the scientific community, which, on the one hand, may be due to the mismatch between the offer of the scientific community and the needs of enterprises and, on the other hand, from the fact that the knowledge of this offer is very poor among entrepreneurs, hence enterprises most often prepare innovations on their own, at most cooperating with other economic entities.

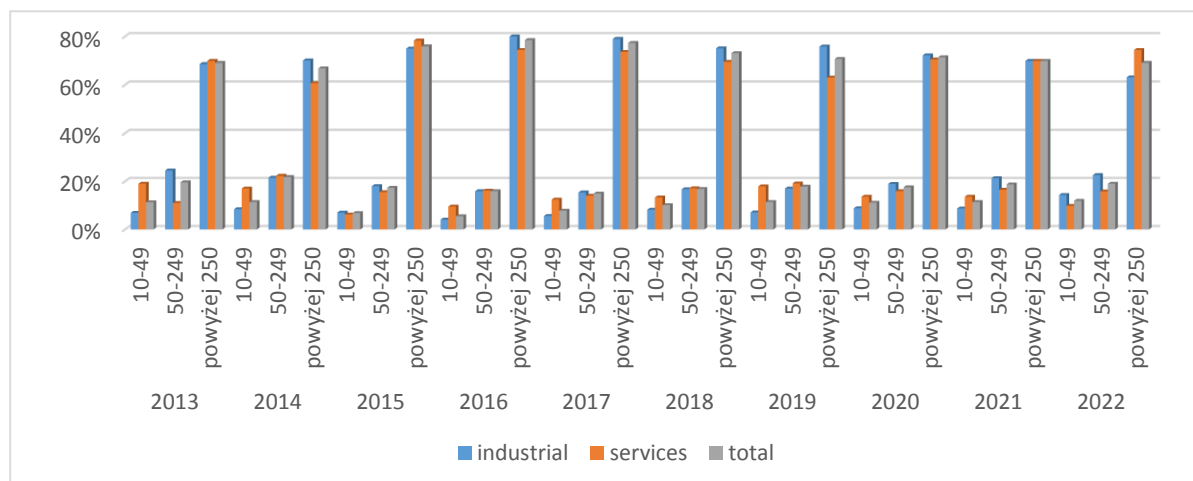


Figure 2. Structure of expenditures on innovation in Poland in 2013-2022.

Source: Own elaboration based on the data of the Central Statistical Office of Poland (CSO).

Due to the scale of their operations, the largest expenditures on innovation were made by large enterprises, whose share ranged from 67% in 2014 to 79% two years later. Innovation expenditures in business units employing between 50 and 249 people accounted for an average of 20%, while in small entities innovation expenditures accounted for about 10%. The highest level of innovation expenditures was recorded in large industrial enterprises, the value of which in total expenditures on the implementation of projects to ensure development represented from 61% in 2014 to as much as 78% the following year. Business units employing more than 250 people, having a higher propensity to take risks and, above all, a significantly larger budget than other entities, generally implemented higher-value projects, including capital-intensive product and process innovations, which in turn translated into their level of innovation activity. In medium-sized industrial enterprises, outlays ranged from 15% in 2017 to 25% in the first studied year, while due to limited capital resources, units with less than 50 employees allocated the least to innovation, and their share of total innovation outlays ranged from just 4% in 2016 to 14% in 2022.

4. Funding Innovations in Polish Enterprises

The most popular form of funding innovative activities of enterprises in Poland, regardless of the size of their operations, is own funds (table 1). Unfortunately, the funding of activities

solely by earned profits, is developing into a significant barrier to development, and is one of the main reasons for the low level of innovation in the Polish economy.

Table 1.

Level and structure of the financing sources for innovative activities in Poland in 2013-2022

		Own		Bank credits		From the state budget		From abroad		Others	
		MLN PLN	%	MLN PLN	%	MLN PLN	%	MLN PLN	%	MLN PLN	%
2013	industrial	14897,8	71	1456,2	7	330,5	2	1897,5	9	2376,9	11
	services	9544,8	80	996,6	8	234	2	999,2	8	206,3	2
2014	industrial	17032,2	69	2487,9	10	400,8	2	2477,5	10	2223,2	9
	services	8701,9	67	1326,8	10	283,3	2	2162,2	17	521	4
2015	industrial	19277,3	62	3574,1	11	626,7	2	2181,2	7	5434,9	18
	services	9221,6	73	789	6	202,1	2	2110,5	17	317,7	4
2016	industrial	20272,4	72	1897,1	7	462,1	2	497,5	2	5175,4	17
	services	9442,9	88	449	4	177,4	2	300,2	3	336,7	4
2017	industrial	21159,4	76	2019,5	7	441,2	2	1029,5	4	3373,9	11
	services	11262	86	537,6	4	278,8	2	506,3	4	557,5	4
2018	industrial	17658,2	75	1892,4	8	722,2	3	1266,9	6	1849	8
	services	11534,2	88	278,2	2	337,2	3	661,7	6	283,5	1
2019	industrial	17386,4	75	1520,8	7	696	3	1384,9	6	2190,8	9
	services	12750	83	568,6	4	364,3	2	1168,5	8	549,4	3
2020	industrial	15404,5	76	1237,6	6	657,1	3	1644	8	1435	7
	services	15697,1	85	705,7	4	260,9	1	1258,7	8	476,9	2
2021	industrial	14527,9	76	1141,2	6	715,8	4	1855,9	10	800,7	4
	services	19639	88	475,5	2	556,6	2	1243,5	6	434,1	2
2022	industrial	19866,8	76	1914,6	7	809,5	3	2387,1	9	1033,7	5
	services	26455,9	89	647	2	543	2	1305,9	4	737,7	3

Source: Own elaboration based on the data of the Central Statistical Office of Poland (CSO).

In 2013 and 2022, industrial enterprises covered the implementation of innovation projects with their own funds worth nearly PLN 177.5 billion. In the first five years of the studied period, the use of funds from this source steadily increased from nearly 14.9 to more than 21 billion zlotys (a 42% increase), with the 2017 value being the highest. In 2018, the trend reversed and the degree of use of own funds decreased to and including 2021 (a decrease of more than 31%), in which expenditures of just over PLN 14.5 billion (the lowest level) were covered from this source. In the last year, the growing trend returned, with nearly PLN 19.9 billion of funds spent by companies in the course of their business on innovation. Taking into account, in turn, the extreme years of the studied period, the use of own funds increased by almost 5 billion zlotys, by more than 33%. The share of use of own funds in funding the innovative activity of industrial enterprises ranged from 62% in 2015 to 75-76% in 2017-2022. In turn, in the studied period, in the service sector enterprises, innovation expenditures of PLN 134.3 billion were covered from their own funds. The lowest level of own funds was recorded in 2014, when the amount of PLN 8.7 billion accounted for 67% of all sources of funding for projects. However, from 2015 to the end of the analyzed period, the use of this source increased with each successive year, and finally in 2022 it amounted to almost PLN 26.5 billion, making the share of own funds as high as 89%. In service companies, which usually implement marketing and

organizational innovations, the value of which is often lower than process and product innovations implemented by industrial entities, the degree of use of own funds was much higher, and their share averaged 83% of the total sources of funding for innovation activity.

During implementation of innovation projects, funds from abroad were used to a much lesser extent. In the entire period covered analyzed, in industrial enterprises subsidies from the EU budget covered nearly PLN 16.6 billion in innovation expenditures. The share of EU funds ranged from 2% in 2016, when the value of subsidies did not even reach half a billion zlotys, to 9-10% in 2013-14 and 2021-2022. The largest amount of funds from this source, at about PLN 2.4 billion, was used in 2014 and 2022. In services sector enterprises, on the other hand, funds raised from abroad totaled PLN 11.7 billion. In 2014-2015, the value of more than 2.1 billion accounted for 17% of all sources of funding for the innovative activity of this group of entities. In other years, the share of EU subsidies was much smaller, ranging from 3% in 2016 to 8% in 2019. At that time, the Smart Growth Programme implemented within the 2013-2020 financial perspective and the European Funds for Modern Economy Programme implemented in the current perspective, as well as regional programs implemented in the respective provinces, were of key importance for entities developing innovative activities. Support for this type of projects, as carrying a risk higher than investment projects, has been a priority for state aid. They were the main source of support for units implementing innovative ventures. Of particular importance was support for the development of SMEs through investments aimed at implementing technological, marketing and organizational innovations. It is worth adding, however, that with non-refundable funding, companies receiving the funds are not obliged to repay them, but nevertheless the condition for receiving them is an own contribution, which entrepreneurs must provide on their own. In addition, the companies receive funds to cover the so-called Eligible Costs, in the form of an advance or reimbursement of expenses, so it covers expenses from its own financial resources in advance. Moreover, as a condition for obtaining subsidy funding, it is necessary to demonstrate the innovativeness of the venture, and sometimes it is also mandatory to share the results of the innovative project in question. Unfortunately, despite the existing opportunities, this causes enterprises that are not very willing to use funds from the national or EU budget, to give up support fearing the accompanying procedures and preliminary requirements.

Even less important, especially in service-sector companies, were funds provided by banks in the form of bank loans. In this group, funds from this source made it possible to cover innovation expenditures worth PLN 6.8 billion. In 2016-2022, the share of bank loans was small and fluctuated between 2-4%, while only in 2014 the amount of just over PLN 1.3 billion accounted for 10% of the total sources of funding for innovation activity. In industrial enterprises, which typically implement more capital-intensive product and process innovations, bank loans financed expenditures of more than PLN 19.1 billion. For these companies, the share of this source of funding was higher than in service entities, averaging 7%, and in 2015, with a value of nearly PLN 3.6 billion, even 11%. The great reluctance to use foreign capital in

innovation activity is due, on the one hand, to a low level of the willingness to undertake financial risks, the desire to have full control over the enterprise, and on the other hand entrepreneurs are afraid of dependence on banks and financial institutions, including private equity funds, so they prefer to develop more slowly, but more safely, having all the activity under control, usually implementing projects whose cost of implementation does not exceed their financial capacity. In addition, companies, especially smaller ones, often have difficult access to capital from financial institutions, associated with the questionable creditworthiness of the borrower, which in turn is reflected in the interest rate and thus the price of the potential loan, as well as in the collateral required for the amount borrowed.

However, the smallest one was the share of funds obtained from the state budget, mainly in the form of bank guarantees, redemption of part of the loan, or special-purpose subsidies, because their share in all the enterprises amount to ca. 2%. Although not included in the lists published by the Central Statistical Office of Poland, companies also used other sources of funding, such as leasing, loans from family and friends, as well as venture capital or support from business angels.

In industrial enterprises from the SME sector, own funds accounted for between 43% in 2015 and 68% in 2021, while in units employing 50-249 people, the degree of using own financial surpluses was significantly higher, ranging from 67% in 2014 to as much as 89% in the last year covered by this analysis. In turn, in small enterprises, own financial resources accounted, on average, for slightly more than half of the sources of funding used for innovation projects. SMEs also used funds obtained from abroad to finance innovation activity, which in 2014 accounted for as much as 26% of all sources, while in 2017-2022 their share was 14-16%. This was undoubtedly due to the fact that a large part of the EU programs related to innovative activities were aimed at this group of entities, which in the indicated period were definitely more often used by units employing up to 49 people. Small businesses also had a relatively high share of bank loans, especially in the years when the amounts of EU funding were the highest, which may have been due to the required own contribution, and the shortage of own financial resources often resulted in the need to take out loans in banks. In large businesses, the main source of funding, i.e. own funds, accounted for between 78% in 2015 and 83% in 2022. The share of other sources was small, ranging from 1% to 6% in the case of funds received from the national or EU budget to about 5% in the case of bank loans (the exception was the amount of more than PLN 2 billion in 2015, which accounted for 10% of the total sources of innovation funding).

After analyzing innovation expenditures, as well as the sources of funding for innovation activity, the relationship between the studied variables was examined, taking into account not only the division into industrial and service enterprises, but also the scale of their activities. The Pearson correlation coefficient was used for this purpose, and the results of the study are presented in tables 2 and 3.

Table 2.*Correlation of financing sources and innovation expenditures in industrial enterprises*

		Correlation				
Sources		Internal sources	Bank credits	From the state budget	From abroad	Others
Scope of business	10-49	0,913069	0,674352	0,435340	0,879134	0,487928
	50-249	0,689339	0,469794	0,108022	0,642105	0,623094
	Over 250	0,947729	0,773652	-0,42416	-0,69616	0,916918

Source: Own elaboration

Taking into account the dependence of innovation expenditures in industrial enterprises on their sources of funding, it can be seen that to the greatest extent the ability to cover innovation expenditures with own funds occurred in small and large enterprises (very high dependence, above 0.9). Access to bank loans was important for entities employing more than 250 people, which implement the most capital-intensive innovations, moreover, they often have an established market position and adequate collaterals for repayment of liabilities, and in entities employing from 10 to 49 people, which could use them to finance the own contribution required in EU subsidies and cover the eligible costs of a given project, as the possibility of obtaining funds from abroad significantly stimulated their innovative activity. In general, small innovative companies were eager to take advantage of various forms of support, and participated in the programs aimed at them and allowing them to obtain EU funding. The significant support was also a grant, the so called “technological bonus” in the form of partial redemption of the credit taken to finance technological innovation. On the other hand, large enterprises, due to the lack of additional support for innovation activity, compensated for the shortage of financial resources with alternative sources of funding, among which venture capital funds were particularly important, constituting an important source of funding for projects. In medium-sized businesses, however, leasing and loans were also an important source supporting innovation activity.

Table 3.*Correlation of financing sources and innovation expenditures in service enterprises*

		Correlation				
Sources		Internal sources	Bank credits	From the state budget	From abroad	Others
Scope of business	10-49	0,933042	0,381944	0,585188	0,818191	0,112648
	50-249	0,986652	0,140540	0,461680	0,778762	0,692017
	Over 250	0,986321	0,181002	0,178995	0,001341	0,151493

Source: Own elaboration.

The innovative activity of enterprises in the service sector, regardless of the size of their operations, was most influenced by their own financial resources, since in all enterprises there is a very high correlation (in small ones 0.93 and in others - close to one) between this source of funding and the level of innovation expenditures. In contrast, service companies with little or no technological background were far less likely to use external capital, which is particularly evident in the case of bank loans, which may have been due to a lack of adequate collaterals.

What is more, the marketing and organizational innovations they implement most often tend to be less capital-intensive, so business units are often able to cover expenses with the profit they generate. Nonetheless, it can be seen that the small entrepreneurs using EU funding, which covered only part of the costs of their projects, were far more likely to depend on funds obtained from financial institutions for their innovation activity. In addition especially during the pandemic, SMEs were eager to take advantage of various forms of support from both the EU and national budgets by implementing innovative solutions that allowed them to survive in the new market realities. Entrepreneurs with an idea of an innovative product, but not having scientific resources to develop it could also benefit from funding granted by Polish Agency for Enterprise Development under the program *Innovation vouchers for SMEs* supporting the entire process of innovation implementation.

5. Summary

Any innovation, no matter what kind of company implements it, involves financial expenses that are often beyond the capacity of the individual company. The need for a specific source of capital is highly dependent on the risk of the venture, the implementation of which requires funding. The ways of obtaining each of the forms of funding also vary, as does their availability, which often depends on additional formal conditions related to access to a particular source (Podstawka, 2020).

Analyzing the structure of funding innovative activities shows that the dominant source is own funds, the high share of which is due to low propensity to take risks, especially in the case of SMEs, as well as to often limited access to external capital and the high cost of obtaining it. The existence of a relationship in this area was confirmed by a correlation study, which, with the exception of medium-sized industrial enterprises, was close to one. Taking into account the external forms of funding, the most significant were the funds obtained from abroad, which was particularly evident in the case of small business entities (correlation of more than 0.8), which, being beneficiaries of many subsidies from EU programs, were eager to supplement the shortage of financial resources. A high correlation also occurred in the case of bank loans, which, in the case of SMEs benefiting from European Union support, earlier allowed coverage of costs that were later reimbursed, while in large industrial entities - they allowed the implementation of technological innovations that required significant expenditures. Medium- and large-sized companies also used alternative forms of funding, such as leasing, loans and VC funds.

References

1. Bał-Woźniak, T. (2020). *Zarządzanie innowacjami w ujęciu podmiotowym*. Warszawa: PWN.
2. Brojakowska-Trzaska, M. (2018). Finansowanie zewnętrzne w działalności mikro- i małych przedsiębiorstw. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu*, No. 533, pp. 44-54.
3. Chen, H., Hai, Q., Wu, K. (2015). Does Financial Constraints Impede Technical Efficiency Improvement? An Empirical Study Based on Micro Data of Manufacturing Firms. *Journal of Financial Research*, Vol. 10, pp. 148-162.
4. Crowley, P. (2004). Innovation in the New Member States and Candidate Countries. Output, Barriers and Protection. *Statistics in Focus, Science and Technology*, No. 13, pp. 1-7.
5. Duraj, J., Papiernik-Wojdera, M. (2010). *Przedsiębiorczość i innowacyjność*. Warszawa: Difin.
6. Fagerberg J., (2005). Innovation a guide to the literature. In: J. Fagerberg, D. Mowery, R. Nelson (Eds.), *The Oxford Handbook of Innovation* (pp. 1-26). Oxford: Oxford University Press.
7. *Innovative activity of enterprises (2013-2022)*. Warszawa: CSO.
8. Janiszewski, D. (2022). Kredyt bankowy jako źródło finansowania przedsiębiorstw w Polsce. *Studia Ekonomiczne, Prawne i Administracyjne*, Vol. 2, pp. 59-69, doi: 10.24136/sepia.2022.009.
9. Jansza, K., Kaczmarska, B., Wasilczuk, J.E. (2020). *Przedsiębiorczość i finansowanie innowacji*. Warszawa: PWE.
10. Kokot-Stępień, P. (2020). Finansowe aspekty zarządzania procesami innowacyjnymi w małych i średnich przedsiębiorstwach. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu*, No. 533, pp. 132-140.
11. Krawczyk, M. (2012). *Finansowanie działalności innowacyjnej MŚP. Wybrane zagadnienia*. Łódź: Wydawnictwo Uniwersytetu Łódzkiego.
12. Krawczyk-Sokołowska, I., Łukomska-Szarek, J. (2017). Public and Private Financing of Innovative Activity of Enterprises in Poland. *Zeszyty Naukowe Politechniki Częstochowskiej, Zarządzanie*, No. 27(2), pp. 50-58.
13. Lewandowska, M.S. (2018). *Koncepcja otwartych innowacji. Perspektywa polskich przedsiębiorstw przemysłowych*. Warszawa: Oficyna Wydawnicza SGH.
14. Makiela, Z. (2013). *Przedsiębiorczość i innowacyjność terytorialna. Region w warunkach konkurencji*. Warszawa: C.H. Beck.

15. Piao, Z., Lin, Y. (2020). Financing innovation and enterprises' efficiency of technological innovation in the internet industry: Evidence from China. *PloS ONE*, Vol. 15, Iss. 9, doi: 10.1371/journal.pone.0239265
16. Podstawka, B. (2020). Źródła finansowania działalności innowacyjnej w Polsce w województwie lubelskim w latach 2015-2018. *Przedsiębiorstwo & Finanse*, No. 1, pp. 39-51.
17. Santos, A.M., Cincera, M., Cerulli, G. (2024). Sources of financing: Which ones are more effective in innovation–growth linkage? *Economic Systems*, Vol. 48, Iss. 2, doi: 10.1016/j.ecosys.2023.101177.
18. *Science and technology* (2013-2022). Warszawa: CSO.
19. Szatkowski, K. (2016). *Zarządzanie innowacjami i transferem technologii*. Warszawa: PWN.
20. Zakrzewska, A., Kijek, T. (2017). Źródła finansowania działalności innowacyjnej przedsiębiorstw przemysłu spożywczego z województwa lubelskiego. *Roczniki Naukowe Stowarzyszenia Ekonomistów Rolnictwa i Agrobiznesu*, Vol. XIX, Vol. 4, pp. 244-249, doi: 10.5604/01.3001.0010.5194.

HUMAN RESOURCES STRATEGIES AND ORGANISATIONAL RESILIENCE IN SELECTED PUBLICLY TRADED COMPANIES

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Aim: The paper examines whether, in the context of changes in terms of progress or regression within the analysed companies, appropriate actions are flexibly implemented in the dimension of human potential. This includes pursuing a human resources (HR) strategy aligned with the overall business strategy and ensuring consistency in various aspects, including recruitment, working time, training and incentive systems, which is one of the conditions for building organisational resilience within the company. In addition, it verifies whether strategic and operational measures are supported by an appropriate organisational culture, focused on embracing change.

Design, methodology and approach: Due to the relevance of the topic, this paper is a continuation of the research conducted by the author in the area of organisational functioning under conditions of change, in the context of building organisational resilience. The article is based on the results of research conducted by the article's author at two of the companies listed on the Warsaw Stock Exchange and research on organisational resilience in the perspective of sustainable development conducted in 2024 by the Department of Enterprise Management at the University of Economics in Katowice. In the both cases, the research was based on analysing responses to questionnaires.

Findings: This article discusses the five obligatory conditions for building organisational resilience in the context of changes related to the company's potential in terms of progress or regression, which can result from an unstable, uncertain environment, focusing primarily on the area concerning the HR strategy.

Practical and social implications: It appears that an effective means, serving as a link for the entire organisation's operations and providing employees with a sense of stability while simultaneously facilitating the organisation's functioning in conditions of volatility, is the application of appropriate measures in the area of HR potential that are consistent with the progress or regression changes.

Originality/value: The study highlights the significance of flexibility of selected aspects of the HR strategy in building organisational resilience, a determinant, identified by the author as fourth in terms of relevance. Every change related to progress or regression requires appropriate actions in the area of human potential, namely an adequate HR strategy and consistent actions in terms of its various aspects, including recruitment, working time, training or the incentive system. The paper describes a case study of a selected publicly traded companies, focusing on selected aspects of the HR strategy, but also organisational culture.

Keywords: organisational resilience, volatility, overall human resources strategy, progress/regression dimension, joint-stock company.

Category of the paper: Viewpoint, General review, Case study.

1. Introduction

The aim of the paper is to highlight the importance of the HR strategy and its aspects in building organisational resilience in practical terms. It attempts to answer the question: “In practical terms, under the conditions of changes in the dimensions of progress and regression, are appropriate measures in the realm of human potential implemented flexibly in the examined company?”. These measures would primarily involve implementing an HR strategy appropriate to the overall business strategy and ensuring consistency in terms of its individual aspects, such as recruitment, working time, training or incentive system. The examples analysed concerns a selected joint-stock companies listed on the Warsaw Stock Exchange. The concept of resilience is understood as the ability of an organisation to anticipate, prepare for and adapt to emerging changes and disruptions in order to survive and continue to develop (British Standard Institution, 2014). Building organisational resilience is a form of response (reaction) to changes, e.g. related to crisis (regression), but also to progress, which initiate a reorientation of the company's existing way of thinking and acting. As noted, an organisation's ability to build resilience can (and even should as the author of this paper observes) be developed through an HR management strategy (Douglas, 2021, p. 2). In many organisations, the HR strategy is increasingly becoming a core component of the overall organisational strategy. HR Management Information Systems are becoming a crucial element of organisational operations, while competency models support recruitment and employee development processes (Dziwulski, Skowron, 2019, p. 43). It was noted more than a decade ago that the HR strategy is an integral part of the organisation's strategy in many companies (Harasim, 2013, p. 26). Moreover, HR departments have become an integral segment of organisations (Harasim, 2013, p. 43).

An HR strategy that is appropriately ‘aligned’ with the overall business strategy can promote the building of organisational resilience. It is important to pay attention to the flexibility of selected aspects of this strategy in this context. Every change related to progress or regression requires appropriate actions in the area of human potential, namely an adequate HR strategy and consistent actions in terms of its various aspects, including recruitment, working time, training or the incentive system (Bujak, Puszko-Machowczyk, 2011, pp. 346-347).

2. Conditions and prerequisites for building organisational resilience

The literature on the subject describes various aspects that can affect resilience (Agostini, Nosella, 2022, pp. 1-14). Disruptive changes force organisations to develop their resilience in a volatile environment if they want to maintain their competitiveness. This paper attempts to answer the question: “How does intellectual capital (i.e. human capital, organisational capital and relational capital) help companies in responding to changing conditions and in seizing emerging opportunities?” Agnostini and Nosella's research is one of the first attempts to clarify the relationship between organisational capital and SME resilience. An important factor in terms of building organisational resilience is an appropriate human resources strategy, adapted to changes in the company's potential in terms of progress or regression (but also in terms of other aspects, such as offensive/defensive or strategical/operational dimensions). This relationship also stems from the need to ensure coherence between the overall business strategy and the HR strategy (which is one of the functional strategies).

In order for companies to be able to build organisational resilience, certain basic conditions should be met. First of all, a necessary prerequisite for building organisational resilience is the existence of a specific relationship between the overall business strategy and the HR strategy. These two strategies are closely interlinked (as part of the so-called interactive approach). People are considered a key element in building competitive advantage within the organisation, rather than merely a 'tool' for implementing the organisation's strategy. There are also cases when the HR strategy is of primary importance in an organisation. People, in this case, are a strategic resource and a factor contributing to gaining competitive advantage and determining the direction for general strategic goals. This is referred to as an active approach (Janowska, 2002, p. 22; Ludwiczynski, Stobińska, 2001, pp. 73-74).

Secondly, a necessary condition is ensuring consistency between the overall business strategy and functional strategies, including the HR strategy. Functional strategies are closely linked to the former. The literature on the subject, in addition to other distinguishing features such as key choices and simplicity, views consistency as one of the characteristics of a strategy. Consistency is analysed in two dimensions: internal and external. The former means that strategic conceptual choices complement each other and that specific choices are aligned with the company's strategy for action. The latter, on the other hand, means alignment with conditions in the external environment. Each choice and the way it is implemented must reinforce the effectiveness of the other choices and actions (Oblój, 2009, p. 6). Internal and external consistency is an indicative sign of a robust strategy, as part of which the company's critical decisions and actions need to complement and reinforce each other, generating positive feedback loops. Hence, the formulation of any functional strategy should be consistent with the overall business strategy (also referred to as the general or global strategy) of the company. For example, when setting company goals and determining how to achieve them,

the overarching objectives serve as the benchmark for defining financial and investment goals. The literature on the subject suggests that different types of strategy (including general strategy and functional strategy) overlap or complement each other (Rostowski, 2003, p. 9). Researchers recognise that there is a relationship between these strategies and “the relationship between personnel strategy and organisational strategy is inextricably linked” (Stalewski, Chlebicka, 1997, p. 31).

Thirdly, another factor influencing the development of organisational resilience in changing conditions (such as unexpected market challenges) is the consistency of partial strategies, including the HR strategy. Research results mentioned in the literature on the subject allow the formulation of specific guidelines concerning the nature of consistency (Malara, Kroik, 2017, p. 28).

The fourth determinant of building organisational resilience is functional flexibility, which refers to the ability to implement multidimensional changes (in terms of progress/regression, market potential, technical production, human resources, organisational, economic and financial aspects) in response to existing, occurring, or anticipated changes within both the organisation's external environment and its internal structure (Bujak, Puszko-Machowczyk, 2011, p. 146). In the dimension of HR management, areas that may be subject to development include recruitment, working time, training and the incentive system. Depending on the HR strategy pursued, these aspects also require consistent action. Achieving consistency, as noted, involves linking complementary actions related to the company's human resources, particularly in areas such as employee recruitment, development, remuneration and evaluation (Tyrańska, 2009, pp. 359-360). The literature also describes the distinguishing characteristics of companies that achieve market success. Among the traits that set successful companies apart from the competitors, it is flexibility that is most often highlighted (Majchrzak, 2020, p. 33).

The fifth condition for building organisational resilience has already been discussed earlier. It involves the essential support of strategic and operational activities through an organisational culture that is geared towards embracing change. This can be, for example, a supportive culture, whereby the organisation's management is oriented towards providing support to individuals and teams. In this case, there is a strong emphasis on shared values and achieving consensus in reaching goals. The basis for action is mutual trust. Employees are made aware that they are an asset to the organisation and are treated as human beings, not just as a resource. They have potential, which – when developed – contributes to better performance of the organisation. Additionally, one of the key roles of organisational culture, specifically its adaptive function, ensures order and a sense of certainty and stability for the organisation, even amidst sudden changes (Ciekanowski, Nowicka, 2014, p. 125).

3. Cultivating human potential in the context of building organisational resilience

Building resilience is closely dependent on having an adequate, comprehensive resource base. This applies to both the company's internal resources and those acquired through partnerships with other entities (Eriksson et al., 2022, p. 209). For larger companies, the proposed approach to aligning strategies with operational actions provides additional opportunities for penetrating and monitoring the effectiveness of HR management (Malara, Kroik, 2017, p. 32).

The above considerations are confirmed by the results of a survey of 211 publicly traded companies conducted in June/July 2024¹. 157 of the companies surveyed (74.76 %) strongly agreed with the statement that human resources in their organisation play a key role in enhancing resilience to unexpected market challenges, 53 (24.76 %) agreed with it, whereas only one company stated that it is difficult to say (0.48%) (cf. Table 1 and Figure 1). The responses to this question confirm the need to implement the aforementioned requirements (see first and second conditions in point 2).

Table 1.

Key role of human resources in increasing the resilience of the surveyed companies to unexpected market challenges

Human resources play a key role in enhancing resilience to unexpected market challenges in our organisation	number of respondents	%
a) strongly agree	157	74.76
b) agree	52	24.76
c) difficult to say	1	0.48
d) disagree	0	0.00
e) strongly disagree	0	0.00
Total	210	100.00

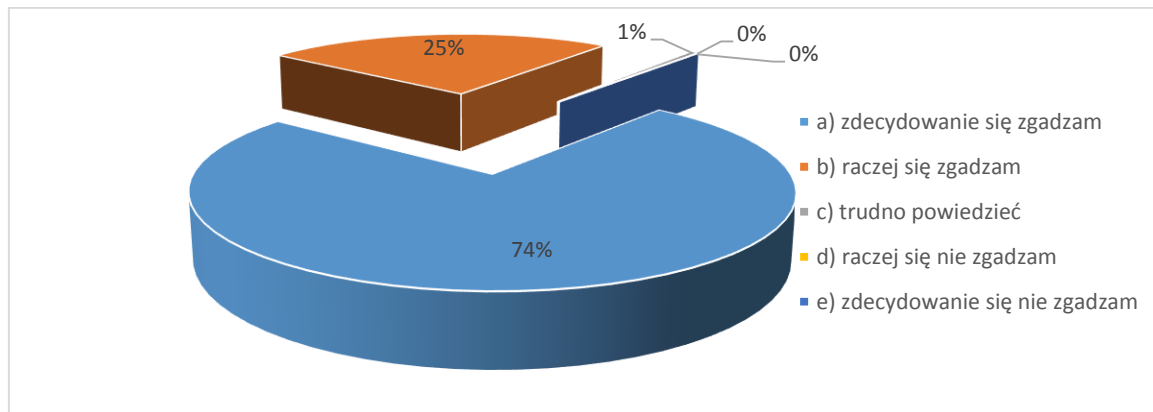
Department of Enterprise Management (2024). Organizational Resilience in the Perspective of Sustainable Development. Research task carried out by the Department of Enterprise Management. Survey Questionnaire. University of Economics in Katowice.

Center for Research and Development (2024). Organizational Resilience in the Perspective of Sustainable Development. Research task carried out by the Department of Enterprise Management. Survey Results. University of Economics in Katowice.

Research Task Manager: Dr. hab. Adam Samborski, Professor of UE Research Task Title: Organizational Resilience in the Perspective of Sustainable Development Years of Research Task Execution: 2023-2024 Unit Implementing the Research Task: Department of Enterprise Management, University of Economics in Katowice.

Source: own elaboration based on: Samborski, 2024.

¹ The study predominantly included large companies, but there were also some medium-sized and small enterprises.



Department of Enterprise Management (2024). Organizational Resilience in the Perspective of Sustainable Development. Research task carried out by the Department of Enterprise Management. Survey Questionnaire. University of Economics in Katowice.

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Figure 1. Key role of human resources in increasing the resilience of the surveyed companies to unexpected market challenges.

Source: Own elaboration based on: Resilience in the Perspective of Sustainable Development. Research task carried out by the Department of Enterprise Management, University of Economics in Katowice.

More than 92 companies (43.81%) surveyed strongly agreed that the organisational culture in their company effectively contributes to managing crises and enhances its resilience to challenges, with a somewhat larger number (97 companies, representing 46.19% of all the companies surveyed) responding that they agree to some extent with that statement. 21 respondents (10% of all the companies surveyed) neither agreed nor disagreed with it. The results shown in Table 2 and Figure 2 present the impact of organisational culture on enhancing the resilience of the companies surveyed. These results suggest the need to implement an appropriate organisational culture that is open to and supports changes from both the external environment and within the organisation itself (cf. fifth condition in point 2).

Table 2.

Effectiveness of organisational culture in managing crises and increasing resilience to challenges in the surveyed companies

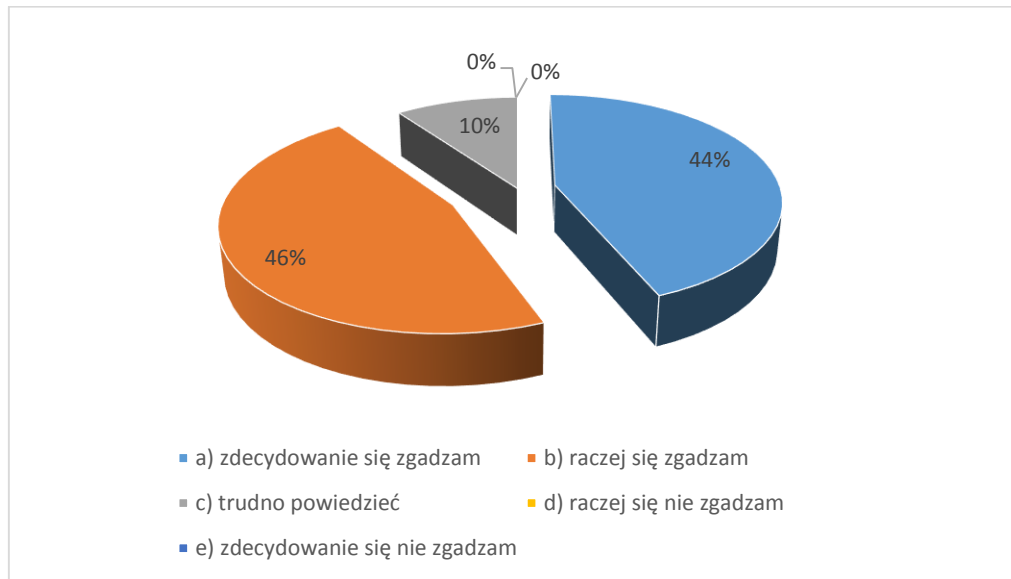
The organisational culture in our company effectively contributes to managing crises and increasing its resilience to challenges	number of respondents	%
a) strongly agree	92	43.81
b) agree	97	46.19
c) difficult to say	21	10.00
d) disagree	0	0.00
e) strongly disagree	0	0.00
Total	210	0.00

Department of Enterprise Management (2024). Organizational Resilience in the Perspective of Sustainable Development. Research task carried out by the Department of Enterprise Management. Survey Questionnaire. University of Economics in Katowice.

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Source: own elaboration based on: Resilience in the Perspective of Sustainable Development. Research task carried out by the Department of Enterprise Management, University of Economics in Katowice.



Department of Enterprise Management (2024). Organizational Resilience in the Perspective of Sustainable Development. Research task carried out by the Department of Enterprise Management. Survey Questionnaire. University of Economics in Katowice.

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Figure 2. Effectiveness of organisational culture in managing crises and increasing resilience to challenges in the surveyed companies.

Source: Own elaboration based on: Resilience in the Perspective of Sustainable Development. Research task carried out by the Department of Enterprise Management, University of Economics in Katowice.

89 (42.38%) of the surveyed companies strongly agreed that their organisation's flexibility and adaptability are directly affected by access to the right resources and competencies, with over 107 companies (50.95%) of the companies agreeing with that statement to some extent. 14 companies (more than 6.66%) neither agreed nor disagreed with this statement (cf. Table 3 and Figure 3). These results can be directly linked to the third and fourth conditions for building organisational resilience, which relate to the flexibility of functional strategies, including the HR strategy (cf. third and fourth conditions in point 2).

Table 3.

Access to adequate resources and competencies as a positive factor affecting the flexibility and adaptability of the surveyed companies

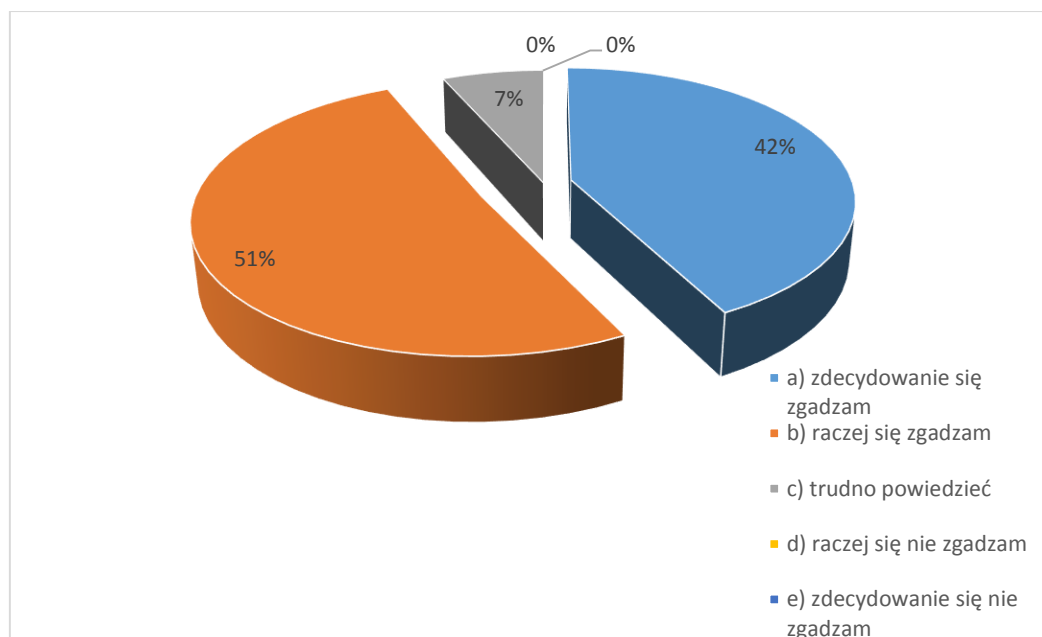
Our organisation's flexibility and adaptability are directly enhanced by access to the right resources and competencies	number of respondents	%
a) strongly agree	89	42.38095
b) agree	107	50.95238
c) difficult to say	14	6.666667
d) disagree	0	0
e) strongly disagree	0	0
Total	210	

Department of Enterprise Management (2024). Organizational Resilience in the Perspective of Sustainable Development. Research task carried out by the Department of Enterprise Management. Survey Questionnaire. University of Economics in Katowice.

Center for Research and Development (2024). Organizational Resilience in the Perspective of Sustainable Development. Research task carried out by the Department of Enterprise Management. Survey Results. University of Economics in Katowice.

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Source: own elaboration based on: Resilience in the Perspective of Sustainable Development. Research task carried out by the Department of Enterprise Management, University of Economics in Katowice.



Department of Enterprise Management (2024). Organizational Resilience in the Perspective of Sustainable Development. Research task carried out by the Department of Enterprise Management. Survey Questionnaire. University of Economics in Katowice.

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Figure 3. Access to adequate resources and competencies as a positive factor affecting the flexibility and adaptability of the surveyed companies.

Source: Own elaboration based on: Resilience in the Perspective of Sustainable Development. Research task carried out by the Department of Enterprise Management, University of Economics in Katowice.

When considering the fourth condition in the context of human potential, it is important to focus on such aspects as recruitment, working time, training and the incentive system. Depending on the HR strategy pursued, these aspects also require consistent action. Attention is also drawn to the role of personnel in shaping organisational resilience through effective recruitment processes and nurturing employee development, which leads to better retention parameters and strengthening employee commitment (higher motivation). One of the key tasks in HR management is attracting the right people to the organisation, as its operation heavily relies on the capabilities of its staff (Piotrowska-Trybull, Sirko, 2024, p. 4). From the perspective of the recruitment process, organisational resilience is demonstrated by the ability to secure a sufficient number of candidates with the specific qualities sought by the employer, who can effectively fulfil the organisation's mission and functions (Piotrowska-Trybull, Sirko, 2024, p. 18). On the other hand, reflecting on previous failures, providing employees with appropriate training on coping techniques and sufficient preparation for crises can lead to improved efficiency, better performance, adaptability, innovation and productivity. These factors, in turn, embody the essence of organisational effectiveness. They also emphasise that while there is extensive research on the relationship between learning in general and organisational effectiveness, studies specifically addressing learning from mistakes and failures, and their impact on future effectiveness, are scarce (Ingram, 2023, pp. 106-107).

The literature also highlights certain categories that serve as indicators of an organisation's focus on human capital. These include, for example, recruiting employees with potential and actively supporting their development, implementing incentive systems based on diverse criteria and motivators, and investing in employee growth (Dziwulski, Skowron, 2019, p. 37), which also increases the chances of retaining them in the organisation.

4. Organisational resilience in the context of market changes – the case studies

The first example cited relates to a joint-stock company that operates in the electromechanical industry specialising in the manufacture and distribution of industrial couplings, drilling equipment and small machinery and equipment for the mining industry². The company offers a wide range of products, including hydrokinetic – fluid, flexible and gear couplings, as well as drilling rigs, pumps and hydraulic power packs. The company supports a variety of industrial sectors such as mining, power generation, shipbuilding and machine

² The study was performed at two companies listed on the Warsaw Stock Exchange in September and October 2024. To obtain the results of the study, a survey questionnaire was prepared which was completed in the first case by the company's Chief Commercial Officer and in the second case by the company's Development Director and sent by email to the author of the article.

industry. It is a manufacturer and distributor of equipment and tools mainly for the mining industry, with a particular focus on the underground mining sector. These are mainly couplings and drilling equipment. It also takes steps to meet the widest possible range of needs of the power generation industry in the field of couplings for all applications. In addition to the mining and power generation industries, the company's range of products is also aimed to a large extent at companies in the engineering, cement, steel and shipbuilding industries³.

With a comprehensive offer for customers operating in different industry sectors, the company aims to increase its share in non-mining markets. The study shows that the company implements a development strategy that is characterised by a constant increase in the quantitative and qualitative potential of the organisation. In addition, the company applies a personnel strategy that is one of the strategies most in line with the overall strategy, i.e. a mixed quantitative and qualitative strategy aimed at increasing the quality of employee competences. This strategy emphasises the numerical and qualitative alignment of the workforce to the needs of the organisation and the qualitative alignment of the workforce to the needs of the organisation (Lipka, 2007, p. 21).

In the company under the study, there is an increase in the level of employment in terms of progress and there is a need for employees with high quality competences. To this end, the company's managers decide to increase the number of substantive training courses for employees. In terms of progress, a so-called aggressive incentive system is implemented characterised by a high proportion of variable pay components and high salary differentiation. In contrast, no action is taking place in the area of working time systems.

Under the conditions of changes made to the company's potential in terms of decline, the company under study implements a personnel strategy that seeks to minimise the extent of the impact of the environment in order to maintain relative stability. This is known as a defensive strategy. In addition, measures to reduce working hours are introduced in a cost-cutting organisation. The number of substantive training courses for employees is declining, while the company is increasing funding for soft skill training. On the other hand, there are no changes in this case in the area of the remuneration system and the staff employment (cf. Table 4).

Table 4 attempts to juxtapose changes in the progress or regression dimension with the corresponding HR strategies in the first company.

³ The information was obtained from the website of the Company under the study.

Table 4.

Changes in the dimension of progress or regression and the corresponding HR strategies in the first company studied

Dimension of change	Changes in the dimension of progress	Changes in the regressive dimension
HR STRATEGIES	QUANTITATIVE AND QUALITATIVE STRATEGY	DEFENSIVE STRATEGY
Employment	increase in level of employment through recruitment	-
Working time	-	narrowing working time
Training:	an increase in funding so-called "hard" training, an increase in the number of training courses for employees	a decrease in the increase in financial expenditure on so-called "hard" training, a reduction in the number of such training courses, the dominance of so-called "soft" training courses
Incentive system	increased motivation through increased investment in motivation, increasing the number and types of motivators, aggressive incentive system	-

Source: own elaboration.

The second example examined concerns a listed company that is the largest in Central Europe and one of the largest in the world producing chains for the mining, fishing, power generation, sugar, cement and timber industries. It operates in all major global market segments. The company specialises in the manufacture of link chains for:

- mining – round and flat mining link chains, shearer loader and road header machine chains, suspension and transport chains, hoist chains, chain assemblies, clamps and flight bars;
- fisheries – trawl chains and others;
- power generation – wear resistant chains, hooks and chain assemblies;
- construction and transportation⁴.

The study shows that the Company implements a personnel strategy aimed at continuous growth, i.e. an offensive strategy. It refers to companies with dynamic growth requiring employees who are creative, innovative and ready to take risks, and therefore numerous candidates with the right skills and qualifications are recruited from the labour market (Tyrańska, 2009, p. 355). In the company under the study, there is an increase in the level of employment in terms of progress and there is a need for employees with high quality competences. To this end – as in the first example provided – decisions are taken to increase the number of substantive training courses for employees. In terms of progress, a so-called aggressive incentive system is implemented characterised by a high proportion of variable pay components and high wage differentiation. In contrast, no action is taking place in the area of the working time system.

⁴ The information was obtained from the website of the Company under the study.

Under the conditions of changes made to the company's potential in terms of decline, the company under study implements a personnel strategy that seeks to minimise the extent of the impact of the environment in order to maintain relative stability, i.e. a defensive strategy. In addition, measures are being introduced to narrow down the working hours, which are being reduced by shaping them accordingly. The number of substantive training courses for employees is decreasing, whereas, according to the reply, there are no changes in the area of the remuneration system and the staff employment (cf. Table 5).

Table 5 attempts to juxtapose changes in the progress or regression dimension with the corresponding HR strategies in the second company.

Table 5.

Changes in the dimension of progress or regression and the corresponding HR strategies in the second company studied

Dimension of change	Changes in the dimension of progress	Changes in the regressive dimension
HR STRATEGIES	OFFENSIVE STRATEGY	DEFENSIVE STRATEGY
Employment	increase in level of employment through recruitment, there is a growing requirement for individuals who possess advanced competencies and expertise.	-
Working time	-	narrowing working time by development of working time systems
Training:	an increase in funding so-called "hard" training, an increase in the number of training courses for employees	a decrease in the increase in financial expenditure on so-called "hard" training, a reduction in the number of such training courses,
Incentive system	an incentive system is introduced which is characterised by a high proportion of mobile remuneration and a large pay differential.	-

Source: own elaboration.

5. Summary

The results of this paper suggest that in order for companies to build organisational resilience amid changes in their potential, whether through progress or regression, certain conditions must be met, including:

1. The existence of an interactive or active relationship between the overall business strategy and the HR strategy, meaning that these strategies evolve together, often with the HR strategy taking a leading role due to employees being a key strategic asset.
2. The implementation of consistent functional strategies, including both HR and overall business strategies.
3. Consistency of the HR strategy itself (i.e. internal consistency).

4. Flexibility of individual elements of the HR strategy, including recruitment, working time, training and the incentive system, in response to changes in the company's potential, whether through progress or regression.
5. Support of strategic and operational activities through an organisational culture that is geared towards embracing change, for example a supportive culture.

Research conducted in 2024 by the Department of Enterprise Management at the University of Economics in Katowice supports the conclusions drawn in the summary. It appears that individuals involved directly or indirectly in crisis management within the surveyed companies are aware of the necessity to build organisational resilience. All the companies surveyed strongly agree or agree to some extent that human resources in their organisation play a key role in enhancing resilience to unexpected market challenges. Furthermore, it appears that organisational culture also contributes effectively to managing crises and enhances the organisation's resilience to external challenges.

References

1. Agostini, L., Nosella, A. (2023). Intellectual capital and resilience: evidence from two cases of SMEs. *Knowledge Management Research & Practice*, 21(5), 929-942.
2. British Standard Institution (2014). BS65000: Guidance on organizational resilience. Source: <https://shop.bsigroup.com/ProductDetail/?pid=0000000000030258792>, 10.08.2024.
3. Bujak, A., Puszko-Machowczyk, K. (2011). Zmiany egzogeniczne determinantą elastyczności organizacji. *Zeszyty Naukowe Wyższej Szkoły Bankowej we Wrocławiu*, 25.
4. Department of Enterprise Management (2024). Organizational Resilience in the Perspective of Sustainable Development. Research task carried out by the Department of Enterprise Management. Survey Questionnaire. University of Economics in Katowice.
5. Center for Research and Development (2024). Organizational Resilience in the Perspective of Sustainable Development. Research task carried out by the Department of Enterprise Management. Survey Results. University of Economics in Katowice.
6. Research Task Manager: Dr hab. Adam Samborski, Professor of UE Research Task Title: Organizational Resilience in the Perspective of Sustainable Development Years of Research Task Execution: 2023 - 2024 Unit Implementing the Research Task: Department of Enterprise Management, University of Economics in Katowice.
7. Dziwulski, J., Skowron, S. (2019). Kapitał ludzki w perspektywie strategicznej i operacyjnej-aspekty metodologii badań. *Studia i Prace Kolegium Zarządzania i Finansów*, 175, 35-48.
8. Eriksson, T., Heikkilä, M., Nummela, N. (2022) Business model innovation for resilient international growth. *Small Enterprise Research*, Vol. 29(3), pp. 205-226.

9. Ingram, T. (2023). *Odporność organizacyjna przedsiębiorstw rodzinnych*. Wydawnictwo Uniwersytetu Ekonomicznego w Katowicach.
10. Janowska, Z. (2002). *Zarządzanie zasobami ludzkimi*. Warszawa: PWE.
11. Kroik, J., Malara, Z., Zdunkiewicz, A. (2017). Spójność strategii personalnej jako determinanta rozwoju przedsiębiorstwa. *Humanitas, Zarządzanie*, 18(3), 9-22.
12. Lipka, A. (2007). Nowe metody wyceny kapitału ludzkiego. *Przegląd Organizacji*, 9, 20-23.
13. Ludwiciński, A. (2001). Metody strategicznego zarządzania zasobami ludzkimi w przedsiębiorstwie. In: A. Ludwiciński, K. Stobiński (ed.), *Zarządzanie strategiczne kapitałem ludzkim*. Warszawa: Poltext.
14. Majchrzak, M. (2020). Odporność przedsiębiorstwa w czasach nadzwyczajnych zagrożeń. Adaptacja koncepcji resilience. *Kwartalnik Nauk o Przedsiębiorstwie*, 54(1).
15. Malara, Z., Kroik, J. (2017). Spójność strategii personalnej organizacji. *Przegląd Organizacji*, 12, 28-33.
16. Malarski, M. (2013). *Konieczność wewnętrznej spójności i dopasowania działań w obszarze zarządzania zasobami ludzkimi*, 155-163.
17. Obłój, K. (2009). Znaczenie spójności strategii. *Przegląd Organizacji*, 9, 6-8.
18. Piotrowska-Trybull, M., Sirko, S. (2024). Pozyskiwanie pracowników jako czynnik wzmacniający odporność organizacji. *Wiedza Obronna*, 286(1).
19. *Resilience in the Perspective of Sustainable Development*. Research task carried out by the Department of Enterprise Management. University of Economics in Katowice.
20. Rostowski, T. (2003). O potrzebie strategii personalnej. *ABC zarządzania zasobami ludzkimi*, 7. *Personel i Zarządzanie*, 10, 3-22.
21. Stalewski, T., Chlebicka, E. (1997). *Zarządzanie zasobami ludzkimi. Wybrane problemy i metody*. Wrocław: Oficyna Wydawnicza Politechniki Wrocławskiej.
22. Survey questionnaire. University of Economics in Katowice, Centre for Research and Development (2024). Organisational resilience in the perspective of sustainable development. Research task carried out by the Department of Enterprise Management. Survey results. University of Economics in Katowice.
23. Tyrańska, M. (2009). Strategie personalne we współczesnych przedsiębiorstwach. *Zeszyty Naukowe Małopolskiej Wyższej Szkoły Ekonomicznej w Tarnowie*, 2(13), 351-362.

THE SUSTAINABLE ENTREPRENEURSHIP AND SOCIO-ECONOMIC COHESION IN POLAND

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Purpose: The basic research hypothesis is as follows “Socio-economic cohesion has a positive, statistically significant impact on the development of sustainable entrepreneurship in Poland from 2008 to 2022”.

Design/methodology/approach: We normalize diagnostic variables into synthetic indicators to verify the hypothesis. We use the classical least squares method (OLS).

Findings: Sustainable entrepreneurship in Poland has a positive trend, although it should be pointed out that the ecological awareness of entrepreneurs should be significantly increased. The results of the study show that social and economic cohesion has a positive impact on sustainable entrepreneurship.

Research limitations/implications: The availability of data, the choice of normalization method and the estimation method for the model.

Social implications: Socio-economic development that considers protecting the natural environment is a source of new entrepreneurial opportunities, generating new profits and solving social and ecological problems. It is a challenge for the entrepreneur, an opportunity, and at the same time, requires a change in the perception and understanding of his role in developing modern economic systems.

Originality/value: The paper's novelty is an attempt to assess the impact of social and economic cohesion on sustainable entrepreneurship in Poland from 2008 to 2022.

Keywords: sustainable entrepreneurship, socio-economic cohesion.

Category of the paper: research paper.

1. Introduction

Sustainable entrepreneurship is entrepreneurship that implements the goals of sustainable development. Socio-economic development that considers protecting the natural environment is a source of new entrepreneurial opportunities, generating new profits and solving social and ecological problems. It is a challenge for the entrepreneur, an opportunity, and at the same time, requires a change in the perception and understanding of his role in developing modern economic systems.

Sustainable entrepreneurship takes place in strictly defined conditions, and its development depends on the social and economic conditions in the country, market conditions and conditions related to the entrepreneur.

The paper's novelty is an attempt to assess the impact of social and economic cohesion on sustainable entrepreneurship in Poland from 2008 to 2022. We want to analyse how cohesion, which aims to promote universal and harmonious development, influences decisions regarding establishing and running a business.

In the context of the objective, the study's main hypothesis is as follows: Socio-economic cohesion has a positive, statistically significant impact on the development of sustainable entrepreneurship in Poland from 2008 to 2022. We created synthetic indicators of sustainable entrepreneurship and socio-economic cohesion to verify the hypothesis. Then, we determined linear correlation indicators, built single-equation models (estimation using the Ordinary Least Square Method: OLS) and a multi-equation model (estimation using the Seemingly Unrelated Regression method: SUR).

The study includes an introduction, materials and methods, research methodology, results, discussion, and conclusion. The review of scientific publications was based on the Scopus and Web of Science lists. The data for the analysis come from Eurostat databases. For the calculations, we used Statistica and Gretl software.

The paper consists of an introduction, a review of the literature on the subject, research methodology, research results, discussion and conclusions.

2. Literature review

Socioeconomic cohesion refers to the degree of unity and interconnectedness within a society, particularly in terms of economic and social factors (Pullano et al., 2020). It encompasses the reduction of disparities between different groups, regions, or individuals in areas such as income, employment, education, and access to services (Nijman et al., 2020). A cohesive society is characterised by strong social bonds, mutual trust, and a sense of shared

purpose among its members. Achieving socioeconomic cohesion involves implementing policies and initiatives that promote equal opportunities, social inclusion, and balanced regional development (Martínez-Virto et al., 2021; Faura-Martínez et al., 2020). This may include measures such as progressive taxation, targeted investment in disadvantaged areas, and programmes to improve social mobility. By fostering socioeconomic cohesion, societies can potentially reduce social tensions, improve overall well-being, and create a more stable and prosperous environment for all citizens (Sánchez et al., 2023; Sielker et al., 2021).

The policy of socioeconomic cohesion is a multifaceted approach aimed at reducing disparities and promoting balanced development across regions and social groups. It is founded on the principle that by equalising opportunities and bolstering human and social capital, societies can achieve greater stability and sustainable economic growth (Davidescu et al., 2024; Sharma, 2023; Mbandlwa, 2023). This policy encompasses various aspects, including healthcare, employment, and infrastructure development. By investing in these areas, policy makers seek to create a more inclusive society where all individuals have access to essential resources and services (Suhaeb et al., 2024; Pavone et al., 2021). The underlying assumption is that a more equitable distribution of opportunities not only benefits disadvantaged groups, but also contributes to the overall prosperity of the entire society. Through targeted interventions and strategic investments, socioeconomic cohesion policies aim to foster social integration, improve economic competitiveness, and ultimately create a more resilient and prosperous society for all its members (Artelaris et al., 2020; Artelaris, 2021; Zhong et al., 2023).

We cannot talk about socioeconomic cohesion without forgetting about sustainable enterprise development, which is emphasised in the subject literature (Villalba-Eguiluz et al., 2020; Kostyukhin, 2019; Misztal, 2022; Mustapa et al., 2018). Corporate sustainability is an approach that integrates economic, social, and environmental goals, enabling companies to generate profits in a way that is responsible for people and the planet. In short, corporate sustainability is based on three pillars: economics, social responsibility, and environmental protection, which together are referred to as the triple bottom line (Misztal, 2023; Roztockii et al., 2020).

Corporate sustainability focusses on generating stable profits while minimising risk (Moore et al., 2009; Baumgartner, 2014). This includes investing in innovation, cost management, ensuring product quality, and customer satisfaction. A sustainable company aims to generate value not only for its owners but also for the local communities and the market in which it operates (Ortiz-de-Mandojana et al., 2016).

Social responsibility is about conducting business in an ethical manner, respecting the rights of employees, providing safe working conditions, and supporting the development of local communities. It can include investing in education, equal rights, equal pay, professional development, and cooperation with local suppliers. Companies that care about their employees,

customers, and society build trust and loyalty, which in the long term has a positive impact on their reputation and success (Tai et al., 2014; Valeri et al., 2019; Naqvi et al., 2021).

Environmental sustainability means that companies strive to minimise their negative impact on the natural environment. This includes effectively managing natural resources, reducing waste, saving energy, reducing CO₂ emissions, and supporting green initiatives such as recycling or renewable energy sources. Examples include investing in environmentally friendly production technology or reducing their carbon footprint. Companies that operate in an environmentally friendly manner often attract customers who care about the environment, which translates into their competitiveness (Uralovich et al., 2023; Jeswani et al., 2020). Corporate sustainability is not only good for companies and society, but is also necessary to address global challenges such as climate change, the depletion of natural resources, and growing social inequality (Oláh et al., 2020).

Socioeconomic cohesion has a significant impact on the sustainable development of enterprises in Poland, as it contributes to the creation of a stable, inclusive and developing market and to reducing social and economic inequalities. In the context of enterprises, this cohesion affects their ability to achieve long-term growth, innovation, and effective management of human and natural resources (Stiglitz, 2016).

Below are some key areas in which socioeconomic cohesion supports the sustainable development of enterprises in Poland (Del-Aguila-Arcentales et al., 2022; Misztal, 2023):

- Improving access to the labour market and increasing human capital.
- Development of infrastructure and equalisation of regional opportunities.
- Increase in Domestic Demand.
- Support for sustainable environmental practices.
- Strengthening public-private partnerships.
- Reducing Social Inequalities and limiting migration.

Activities for socioeconomic cohesion, such as investments in education, vocational training, and social integration, increase the qualifications of employees and their adaptation to the requirements of the labour market (Martínez-Virto et al., 2021). This results in better access to a qualified workforce, which strengthens the innovation and productivity of enterprises. Improving the quality of human capital promotes the growth of companies' competitiveness and allows them to better adapt to changing market conditions (Sánchez et al., 2023).

Investments in road, communication, and digital infrastructure, often supported by EU and state funds, make it easier for companies operating in less developed regions of Poland to access new markets, resources, and technologies. Better infrastructure reduces operating costs, increases efficiency, and attracts investors, which allows companies to operate on more equal terms regardless of location (V et al., 2023; Pavone et al., 2021).

Socioeconomic cohesion reduces income inequalities, which affects the growth of household purchasing power. As a result, the demand for goods and services on the domestic market increases, creating new development opportunities for companies operating locally. The financial stability of consumers facilitates long-term investment planning and increases revenues that can be allocated to innovation or expansion (Akinsulire et al., 2024).

Socioeconomic cohesion contributes to the development of companies based on the principles of sustainable development, especially in the context of responsible environmental management. Grants and relief for companies that implement ecological and energy-efficient solutions encourage sustainable development, which has a positive impact on the reputation of companies and reduces their impact on the environment (Appannan et al., 2023). Companies in Poland are increasingly motivated to invest in environmentally friendly technologies, which translates into savings and better management of natural resources (Tutko, 2023).

In Poland, socioeconomic cohesion also contributes to the development of partnerships between the public and private sectors, especially in areas related to infrastructure, education, and innovation. Such partnerships help companies obtain financing, technology, and know-how that support their sustainable development. Joint initiatives can also reduce investment risk and contribute to market stabilisation (Kuzior et al., 2020; Dubravská et al., 2020).

Socioeconomic cohesion reduces differences in the standard of living in different regions of the country, which reduces migration of people to large cities and abroad. Due to this, companies have access to a more stable labour market and do not struggle with the outflow of talent, which is especially beneficial for smaller companies operating in less urbanised regions (Giannakis et al., 2020).

In summary, socioeconomic cohesion in Poland is a key factor supporting the sustainable development of enterprises, contributing to the creation of equal opportunities and a stable business environment (Lewandowska et al., 2021; Oláh et al., 2020). The long-term effects of this cohesion can lead to an increase in the competitiveness of Polish companies on the international stage and to the strengthening of the national economy in a sustainable and responsible way.

3. Research methodology

We conducted the research for data on the Polish economy. The data for the study was taken from the Eurostat database, they are annual. The basic research hypothesis is as follows “Socio-economic cohesion has a positive, statistically significant impact on the development of sustainable entrepreneurship in Poland from 2008 to 2022”. Our research has several steps:

- we created indicators of sustainable entrepreneurship and social and economic cohesion,
- we conducted correlation analysis,
- we built single- and multi-equation models.

We calculated the economic cohesion (EC) indicator based on analytical indicators divided into two groups:

- stimulants: gross domestic product at market prices [current prices, million euro], exports of goods and services [current prices, million euro], value of goods and materials sold [PLN thousand], R&D [PLN million], total industrial production sold,
- destimulants: Imports of goods and services [Current prices, million euro] Consumer price index, Total debt [PLN million].

We determined the social cohesion (SC) indicator based on the following:

- stimulants: employment level, average monthly gross wages [PLN] % of women sitting in the Sejm of the Republic of Poland [%], % of people over 25 years of age with primary education, % of people over 25 years of age with higher education, average life expectancy, population connected to public water supply [%];
- destimulants: Gini coefficient, unemployment rate [%], at risk of poverty rate (cut-off point: 60% of median equivalised income after social transfers) [%].

The sustainable entrepreneurship indicator ($SuSE$) is divided into three pillars:

- economic pillar (E):
 - stimulants distinguished: enterprises – number, turnover or gross premiums written, production value, value added at factor cost, gross operating surplus, total purchases of goods and services, gross investment in tangible goods, gross operating surplus/turnover (gross operating rate), share of gross operating surplus in value added, investment (investment/value added rate at factors cost),
 - destimulants: share of personnel costs in production, average personnel costs (personnel costs per employee);
- social pillar (S):
 - stimulants: wages and salaries, social security costs, employees – number, turnover per person employed, apparent labor productivity, wage adjusted labor productivity, gross value added per employee, growth rate of employment, persons employed per enterprise, investment per person employed,
 - destimulants: personnel costs, share of personnel costs in total purchases of goods and services;
- environmental pillar (Env): environmental destimulants, carbon dioxide emission, methane emission, nitrous oxide emission, sulfur oxides emission, ammonia emission, carbon monoxide emission, nitrogen oxides emission, generation of total waste.

Then, we transform the explanatory variables into integrated to create $SuSE$, using the following formulas (Pieloch et al., 2020):

- for the stimulants:

$$Z_{ij} = \frac{x_{ij} - \min_i \{x_{ij}\}}{\max_i \{x_{ij}\} - \min_i \{x_{ij}\}}, Z_{ij} \in [0; 1] \quad (1)$$

- for the destimulants:

$$Z_{ij} = \frac{\max_i \{x_{ij}\} - x_{ij}}{\max_i \{x_{ij}\} - \min_i \{x_{ij}\}}, Z_{ij} \in [0; 1] \quad (2)$$

where:

Z_{ij} stands for the normalized value of the j -th variable in the i -th year;

x_{ij} is the diagnostic variable in i -year.

To calculate SC and EC, we assume the same impact of different indices on the aggregate measure. We use the following formula:

$$SC_i; EC_i = \frac{\sum_{j=1}^n \text{IntVar}_{ij}}{n}, (i = 1, 2, \dots, n) \quad (3)$$

where IntVar_i – integrated variable in i -year.

We use the following formula to create the Sus_E :

$$Sus_E = \frac{E+S+Env}{L} = \frac{\sum_{i=1}^n \frac{E_{ij}}{n} + \sum_{i=1}^n \frac{S_{ij}}{n} + \sum_{i=1}^n \frac{Env_{ij}}{n}}{L}, Sus_E \in [0; 1] \quad (4)$$

where:

L is the working-age population;

z_{ij} is the normalized value of variable j in year i .

We use the OLS method to estimate models, which are given by the equations:

$$EE; SE; EnvE = \hat{\beta}_0 + \hat{\beta}_1 \cdot SC_i + \varepsilon_i \quad (5)$$

$$EE; SE; EnvE = \hat{\beta}_0 + \hat{\beta}_1 \cdot EC_i + \varepsilon_i \quad (6)$$

$$SusE = \hat{\beta}_0 + \hat{\beta}_1 \cdot EC_i + \hat{\beta}_2 \cdot SC_i + \varepsilon_i \quad (7)$$

where:

β_0 is the intercept,

$\beta_1; \beta_2; \beta_3$ is the slope,

ε_i denotes the i -th residual,

i is an observation index.

The regression is written with the formula:

$$s(\hat{\beta}_0, \dots, \hat{\beta}_2) = \sum_{i=1}^n e_i^2 = \sum_{i=1}^n (I_i - \hat{I}_i)^2 \rightarrow \min$$

$$s(\hat{\beta}_0, \dots, \hat{\beta}_4) = \sum_{i=1}^n (Sus_E - \hat{\beta}_0 - \hat{\beta}_1 \cdot EC_i - \hat{\beta}_2 \cdot SC_i - \varepsilon_i)^2 \rightarrow \min$$
(8)

We create the structural equation model and use the SUR method to estimate it:

$$\begin{aligned}
 EE &= \alpha_0 + \alpha_1 \cdot SE + \alpha_2 \cdot ENVE + \alpha_3 \cdot SC + \alpha_4 \cdot SC(t-1) + \alpha_5 \cdot SC(t-2) + \alpha_6 \cdot EC + \alpha_7 \cdot EC(t-1) + \alpha_8 \cdot EC(t-2) + \varepsilon_i \\
 SE &= \alpha_0 + \alpha_1 \cdot EE + \alpha_2 \cdot ENVE + \alpha_3 \cdot SC + \alpha_4 \cdot SC(t-1) + \alpha_5 \cdot SC(t-2) + \alpha_6 \cdot EC + \alpha_7 \cdot EC(t-1) + \alpha_8 \cdot EC(t-2) + \varepsilon_i \\
 ENVE &= \alpha_0 + \alpha_1 \cdot EE + \alpha_2 \cdot SE + \alpha_3 \cdot SC + \alpha_4 \cdot SC(t-1) + \alpha_5 \cdot SC(t-2) + \alpha_6 \cdot EC + \alpha_7 \cdot EC(t-1) + \alpha_8 \cdot EC(t-2) + \varepsilon_i
 \end{aligned}$$
(9)

SUR method estimator:

$$\sqrt{R} \cdot (\hat{\beta} - \beta) \xrightarrow{d} N(0, (\frac{1}{R} \cdot X^T \cdot (\sum -1 \otimes I_R) \cdot X)^{-1})$$
(10)

where:

R – observation number,

Ω – covariance matrix,

X – equations,

I_R – dimensional identity matrix,

$\otimes$ – denotes matrix Kronecker product,

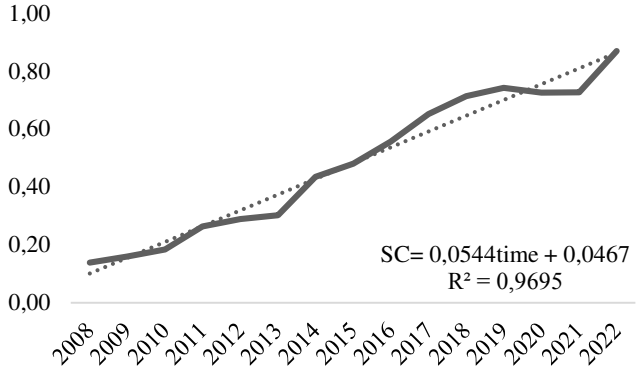
$\hat{\Sigma}$ – matrix,

y – vector.

4. Research results

The social cohesion index in Poland in 2008-2022 has a positive trend (index increase). In the given period, its average value is 0,48 (standard deviation 0,24; median 0,48), while the maximum value is 0,87 (2022), and the minimum value is 0,14 (2008) (Table 1).

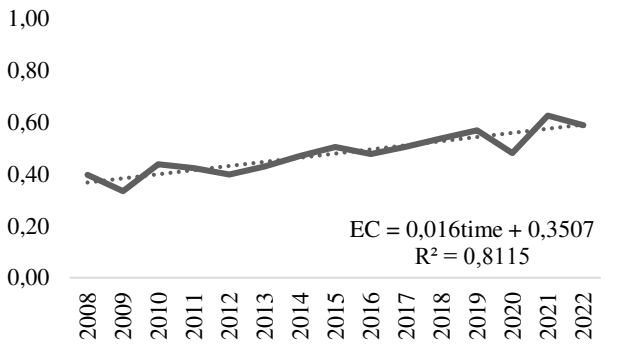
Table 1.*Index of social cohesion in Poland (2008-2022)*

Poland		
Year	Index of social cohesion	Trend line
2008	0,14	
2009	0,16	
2010	0,18	
2011	0,26	
2012	0,29	
2013	0,30	
2014	0,43	
2015	0,48	
2016	0,56	
2017	0,65	
2018	0,71	
2019	0,74	
2020	0,73	
2021	0,73	
2022	0,87	
Descriptive statistics		
Mean	0,48	
Standard deviation	0,24	
Median	0,48	
Min	0,14	
Max	0,87	

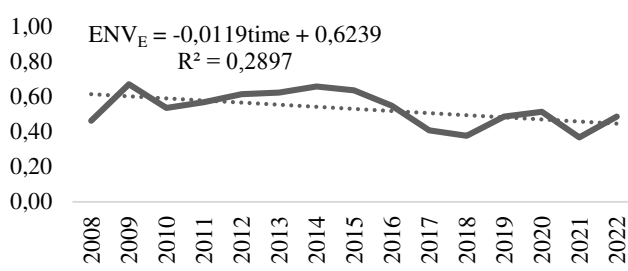
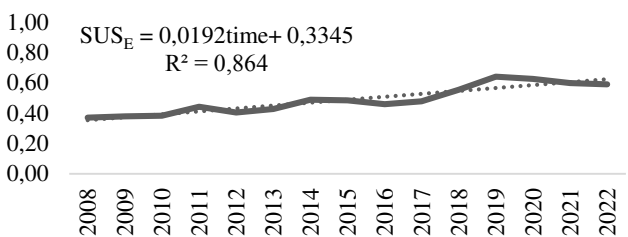
Source: own study on the basis of Eurostat <https://ec.europa.eu/Eurostat>; <https://stat.gov.pl/>, 8.11.2024.

The index of economic cohesion in Poland from 2008 to 2022 shows a positive trend, which means its growth. In the period under review, its average value is 0,48 (standard deviation 0,08; median 0,48), while the maximum value is 0,62 (2021), and the minimum value is 0,33 (2009) (Table 2).

Table 2.*Index of economic cohesion in Poland (2008-2022)*

Poland		
Year	Index of economic cohesion	Trend line
2008	0,40	 $EC = 0,016time + 0,3507$ $R^2 = 0,8115$
2009	0,33	
2010	0,44	
2011	0,42	
2012	0,40	
2013	0,43	
2014	0,47	
2015	0,50	
2016	0,48	
2017	0,51	
2018	0,54	
2019	0,57	
2020	0,48	
2021	0,62	
2022	0,59	

Cont. table 3.

Environmental entrepreneurship	0,46	0,67	0,53	0,57	0,61	0,62	0,65	0,63	0,55	0,41	0,38	0,48	0,51	0,37	0,49
Descriptive statistics	Trend line														
Mean	0,53														
Standard deviation	0,10														
Median	0,53														
Min	0,37														
Max	0,67														
Sustainable entrepreneurship	0,37	0,38	0,38	0,44	0,40	0,43	0,49	0,48	0,46	0,48	0,55	0,64	0,63	0,60	0,59
Descriptive statistics	Trend line														
Mean	0,49														
Standard deviation	0,09														
Median	0,48														
Min	0,37														
Max	0,64														

Source: own study on the basis of Eurostat <https://ec.europa.eu/Eurostat>, <https://stat.gov.pl/>, 8.11.2024.

The Pearson's R, Spearman's Rho, Gamma and Kendall rank correlation coefficients between the sustainable entrepreneurship index and social and economic cohesion indexes in Poland in 2008-2022 are statistically significant ($p < 0,05$, bolded in Table 4). There is a positive relationship between these variables and different levels of correlation coefficients regarding the strength of impact (strong correlation). The highest level of the correlation coefficient is between the index of sustainable entrepreneurship and the index of social cohesion in Poland in 2008-2022 – 0.93 (Spearman's Rho) (Table 4).

Table 4.

Pearson's R, Spearman's Rho, Gamma and Kendall rank correlation coefficients in the period from 2008 to 2022, $p < 0,05$ ($n = 15$)

Index	Correlation coefficient			
	Pearson's R	Spearman's Rho	Gamma	Kendall rank
SUS _E /SC	0,92	0,93	0,79	0,79
SUS _E /EC	0,85	0,87	0,70	0,70

Source: own study on the basis of Eurostat <https://ec.europa.eu/Eurostat>, <https://stat.gov.pl/>, 8.11.2024.

The results of OLS regression between the components of the index of sustainable entrepreneurship (economic, social, and environmental entrepreneurship) and social and economic cohesion indexes in Poland in 2008-2022 indicate a statistically significant relationship. The relationship between the examined variables is positive or negative, with a different level of strength. The highest positive level of relationship is between the index of economic entrepreneurship and economic cohesion index in Poland in 2008-2022, 2.14,

and the lowest positive level of relationship is between the index of social entrepreneurship and social cohesion index in Poland in 2008-2022, 0.55. The highest negative level of relationship is between the index of environmental entrepreneurship and economic cohesion index in Poland in 2008-2022, -0.81, and the lowest negative level of relationship is between the index of environmental entrepreneurship and social cohesion index in Poland in 2008-2022, -0.23. The results meet the OLS estimation conditions, including no collinearity, homoscedasticity, normal distribution of variables, and no autocorrelation (Table 5).

Table 5.

Results of the OLS regressions in the period from 2008 to 2022 ($p < 0,05$)

$$EE = \alpha_0 + \alpha_1 \cdot SC + \varepsilon_i$$

$$EE = \alpha_0 + \alpha_1 \cdot EC + \varepsilon_i$$

$$SE = \alpha_0 + \alpha_1 \cdot SC + \varepsilon_i$$

$$SE = \alpha_0 + \alpha_1 \cdot EC + \varepsilon_i$$

$$ENVE = \alpha_0 + \alpha_1 \cdot SC + \varepsilon_i$$

$$ENVE = \alpha_0 + \alpha_1 \cdot EC + \varepsilon_i$$

Dependent variable	Independent variable	Coefficient	Std. error	P-value	R-squared
E_E	Const	0,12	0,05	0,0500	0,81
	SC	0,71	0,10	<0,0001	
E_E	Const	-0,56	0,17	0,0100	0,74
	EC	2,14	0,35	<0,0001	
S_E	Const	0,21	0,03	<0,0001	0,89
	SC	0,55	0,05	<0,0001	
S_E	Const	-0,31	0,10	0,0100	0,82
	EC	1,64	0,22	<0,0001	
ENV_E	Const	0,64	0,05	<0,0001	0,33
	SC	-0,23	0,09	0,0200	
ENV_E	Const	0,92	0,13	<0,0001	0,43
	EC	-0,81	0,26	0,0100	

Source: own study on the basis of Eurostat <https://ec.europa.eu/eurostat>, <https://stat.gov.pl/>, 8.11.2024.

The results of OLS regression between the index of sustainable entrepreneurship and social and economic cohesion indexes in Poland in 2008-2022 indicate a statistically significant relationship. The relationship between the examined variables is positive and has a different level of strength. The highest level of relationship is between the index of sustainable entrepreneurship and economic cohesion index in Poland in 2008-2022, 0.99, and the lowest level of relationship is between the index of sustainable entrepreneurship and social cohesion index in Poland in 2008-2022, 0.34. The results meet the OLS estimation conditions (Table 6).

Table 6.

Results of the OLS regressions in the period from 2008 to 2022 ($p < 0,05$)

$$SUSE = \alpha_0 + \alpha_1 \cdot SC + \varepsilon_i$$

$$SUSE = \alpha_0 + \alpha_1 \cdot EC + \varepsilon_i$$

Dependent variable	Independent variable	Coefficient	Std. error	P-value	R-squared
SUS_E	Const	0,32	0,02	<0,0001	0,85
	SC	0,34	0,04	<0,0001	
SUS_E	Const	0,02	0,08	0,8600	0,72
	EC	0,99	0,17	<0,0001	

Source: own study on the basis of Eurostat <https://ec.europa.eu/eurostat>, <https://stat.gov.pl/>, 8.11.2024.

The results of the SUR estimation indicate that the social and economic cohesion indexes in Poland in 2008-2022 (or the same indexes t-1, t-2) have a statistically significant, positive or negative influence on components of the index of sustainable entrepreneurship in Poland in 2008-2022 (economic, social, and environmental entrepreneurship).

Table 7.

Results of SUR regressions in the period from 2008 to 2022

$$EE = \alpha_0 + \alpha_1 \cdot SE + \alpha_2 \cdot ENVE + \alpha_3 \cdot SC + \alpha_4 \cdot SC(t-1) + \alpha_5 \cdot SC(t-2) + \alpha_6 \cdot EC + \alpha_7 \cdot EC(t-1) + \alpha_8 \cdot EC(t-2) + \varepsilon_i$$

$$SE = \alpha_0 + \alpha_1 \cdot EE + \alpha_2 \cdot ENVE + \alpha_3 \cdot SC + \alpha_4 \cdot SC(t-1) + \alpha_5 \cdot SC(t-2) + \alpha_6 \cdot EC + \alpha_7 \cdot EC(t-1) + \alpha_8 \cdot EC(t-2) + \varepsilon_i$$

$$ENVE = \alpha_0 + \alpha_1 \cdot EE + \alpha_2 \cdot SE + \alpha_3 \cdot SC + \alpha_4 \cdot SC(t-1) + \alpha_5 \cdot SC(t-2) + \alpha_6 \cdot EC + \alpha_7 \cdot EC(t-1) + \alpha_8 \cdot EC(t-2) + \varepsilon_i$$

Country	Dependent variable	Independent variable	Coefficient	Std. error	p-value	R ²
Poland	E _E	Const	-0,38	0,07	0,0005	0,99
		S _E	1,62	0,12	6,41E-07	
		SC _(t-1)	-0,73	0,16	0,0017	
		SC _(t-2)	0,56	0,14	0,0036	
		EC _(t-2)	0,33	0,16	0,0490	
	S _E	Const	0,24	0,03	0,0001	0,99
		E _E	0,61	0,04	6,28E-07	
		SC _(t-1)	0,44	0,09	0,001	
		SC _(t-2)	-0,33	0,09	0,0063	
		EC _(t-1)	-0,20	0,09	0,0445	
	ENV _E	Const	0,37	0,16	0,0409	0,59
		SC _(t-2)	-0,53	0,14	0,0043	
		EC _(t-1)	0,81	0,43	0,0885	

Source: own study on the basis of Eurostat <https://ec.europa.eu/Eurostat>, <https://stat.gov.pl/>, 8.11.2024.

The highest positive level of relationship is between the index of economic entrepreneurship and social cohesion index in Poland in 2008-2022, 1.62, and the lowest positive level of relationship is between the index of economic entrepreneurship and economic cohesion index in Poland in 2008-2022(t-2), 0.33. The highest negative level of relationship is between the index of economic entrepreneurship and social cohesion index in Poland in 2008-2022(t-1), -0.73, and the lowest negative level of relationship is between the index of social entrepreneurship and economic cohesion index in Poland in 2008-2022(t-1), -0.23 (Table 7).

5. Discussion

Sustainable entrepreneurship is important for sustainable development based on three economic, social and environmental goals. Sustainable entrepreneurship requires, on the one hand, a detailed business plan that will take into account the internal conditions of the enterprise, its skills and its attitude to social and environmental issues, but on the other hand, it is dependent on several external factors (Kostyukhin, 2019; Misztal, 2023).

Our research indicates that the increase in social and economic cohesion contributes to the sustainable development of entrepreneurship (Matera et al., 2023). Therefore, the main research hypothesis is true because the impact of cohesion on sustainable entrepreneurship is positive.

Like other researchers, we have noticed that sustainable entrepreneurship has a small positive trend in Poland, although its level still needs to be satisfactory (Kowalska et al., 2024).

Additionally, the level of economic and social cohesion is increasing in Poland, which should be interpreted as a positive phenomenon of improving the general macrosocial situation in Poland, associated with improving living conditions and quality of life.

Sustainable entrepreneurship is developing by a small positive trend, with its economic and social pillars having a positive trend and the environmental pillar having a negative one; this means that Polish entrepreneurs still need to fully exploit the opportunities offered by running a business through environmental protection.

The results of correlations and estimations of the OLS and SUR show that social and economic cohesion affects sustainable entrepreneurship and its pillars in various ways.

The research has limitations related to the selection of indicators for analysis, the choice of estimation methods and the construction of synthetic indicators.

Empirical implications concern the construction of indicators and the development of econometric models that allow for the assessment of the development of sustainable entrepreneurship in Poland. The contribution to the theory is developing a literature review and proposing our own research method.

6. Conclusion

Sustainable entrepreneurship is entrepreneurship that considers economic, social and environmental goals. It is extremely important for stable and lasting development that improves the quality of life.

Sustainable entrepreneurship in Poland has a positive trend, although it should be pointed out that the ecological awareness of entrepreneurs should be significantly increased. The results of the study show that social and economic cohesion has a positive impact on sustainable entrepreneurship. Therefore, macroeconomic conditions and social issues should be analyzed when dealing with economic activity.

We will devote further research to analyzing sustainable entrepreneurship in the European Union countries to compare the situation and indicate key factors for further development.

References

1. Akinsulire, A.A., Idemudia, C., Okwandu, A.C., Iwuanyanwu, O. (2024). Strategic planning and investment analysis for affordable housing: Enhancing viability and growth. *Magna Scientia Advanced Research and Reviews*, 11(2), 119-131. <http://dx.doi.org/10.30574/msarr.2024.11.2.0114>
2. Appannan, J.S., Mohd Said, R., Ong, T.S., Senik, R. (2023). Promoting sustainable development through strategies, environmental management accounting and environmental performance. *Business Strategy and the Environment*, 32(4), 1914-1930. <http://dx.doi.org/10.1002/bse.3227>
3. Artelaris, P. (2021). Regional economic growth and inequality in Greece. *Regional Science Policy & Practice*, 13(1), 141-159. <http://dx.doi.org/10.1111/rsp3.12363>
4. Artelaris, P., Mavrommatis, G. (2020). Territorial cohesion as a policy narrative: From economic competitiveness to 'smart' growth and beyond. *Social Inclusion*, 8(4), 208-217. <http://dx.doi.org/10.17645/si.v8i4.3336>
5. Baumgartner, R.J. (2014). Managing corporate sustainability and CSR: A conceptual framework combining values, strategies and instruments contributing to sustainable development. *Corporate Social Responsibility and Environmental Management*, 21(5), 258-271. <http://dx.doi.org/10.1002/csr.1336>
6. Davidescu, A.A., Nae, T.M., Florescu, M.S. (2024). From Policy to Impact: Advancing Economic Development and Tackling Social Inequities in Central and Eastern Europe. *Economies*, 12(2), 28. <https://doi.org/10.3390/economies12020028>
7. Del-Aguila-Arcentales, S., Alvarez-Risco, A., Jaramillo-Arévalo, M., De-la-Cruz-Diaz, M., de las Mercedes Anderson-Seminario, M. (2022). Influence of social, environmental and economic sustainable development goals (SDGs) over continuation of entrepreneurship and competitiveness. *Journal of Open Innovation: Technology, Market, and Complexity*, 8(2), 73. <http://dx.doi.org/10.3390/joitmc8020073>
8. Dubravská, M., Marchevská, M., Vašaničová, P., Kotulič, R. (2020). Corporate social responsibility and environmental management linkage: An empirical analysis of the Slovak Republic. *Sustainability*, 12(13), 5431. <http://dx.doi.org/10.3390/su12135431>
9. Faura-Martínez, Ú., Lafuente-Lechuga, M., García-Luque, O. (2020). Social and territorial cohesion in Spain: relevance of the socioeconomic context. *Social Indicators Research*, 150(2), 501-547. <https://link.springer.com/article/10.1007/s11205-020-02308-9>
10. Giannakis, E., Bruggeman, A. (2020). Regional disparities in economic resilience in the European Union across the urban–rural divide. *Regional Studies*, 54(9), 1200-1213. <https://doi.org/10.1080/00343404.2019.1698720>

11. Jeswani, H.K., Chilvers, A., Azapagic, A. (2020). Environmental sustainability of biofuels: a review. *Proceedings of the Royal Society A*, 476(2243), 20200351. <https://doi.org/10.1098/rspa.2020.0351>
12. Kostyukhin, Y. (2019). Conceptual provisions of sustainable development of socio-economic systems (on the example of an industrial enterprise). *International Multidisciplinary Scientific GeoConference: SGEM*, 19(5.3), 131-138. 10.5593/sgem2019/5.3/S21.017
13. Kowalska, M., Misztal, A., Matera, R. (2024). Wpływ bezpieczeństwa ekonomicznego na zrównoważoną przedsiębiorczość w Europie Środkowo-Wschodniej – od kryzysu finansowego do pandemii COVID-19. *Comparative Economic Research. Central and Eastern Europe*, 27(1), 67-92. <https://doi.org/10.18778/1508-2008.27.04>
14. Kuzior, A., Lobanova, A. (2020). Tools of information and communication technologies in ecological marketing under conditions of sustainable development in industrial regions (through examples of Poland and Ukraine). *Journal of risk and financial management*, 13(10), 238. <https://doi.org/10.3390/jrfm13100238>
15. Lewandowska, A., Szymańska, D. (2021). Ecologisation of Polish cities in the light of selected parameters of sustainable development. *Sustainable Cities and Society*, 64, 102538. <http://dx.doi.org/10.1016/j.scs.2020.102538>
16. Martínez-Virto, L., Sánchez-Salmerón, V. (2021). Regional responses to social changes in Spain. Trends and policy challenges for social cohesion. *Regional Science Policy & Practice*, 13(5), 1407-1422. <https://doi.org/10.1111/rsp3.12330>
17. Matera, R., Misztal, A., Kowalska, M. (2023). Sustainable entrepreneurship and its determinants. The case of selected Central Eastern European Countries: From the global financial crisis to the COVID-19 pandemic. *Ekonomista*, 4. <https://doi.org/10.52335/ekon/174760>
18. Mbandlwa, Z. (2023). Socioeconomic Impact of Policy-Making in South Africa. *Journal of Law and Sustainable Development*, 11(10), e1799-e1799. <http://dx.doi.org/10.55908/sdgs.v11i10.1799>
19. Misztal, A. (2022). Sustainable development of manufacturing enterprises in the socio-economic context. The case of Poland and Germany. *Optimum. Economic Studies*, 108(2), 67-79. <https://doi.org/10.15290/oes.2022.02.108.05>
20. Misztal, A. (2023). The sustainable development of enterprises in Poland during the war in Ukraine geopolitical and socio-economic crises–PESTEL and SWOT analysis. *Optimum. Economic Studies*, 114(4), 189-202. <https://doi.org/10.15290/oes.2023.04.114.11>
21. Moore, S.B., Manring, S.L. (2009). Strategy development in small and medium sized enterprises for sustainability and increased value creation. *Journal of cleaner production*, 17(2), 276-282. <https://doi.org/10.1016/j.jclepro.2008.06.004>

22. Mustapa, W.N.B.W., Al Mamun, A., Ibrahim, M.D. (2018). Development initiatives, micro-enterprise performance and sustainability. *International Journal of Financial Studies*, 6(3), 74. <https://doi.org/10.3390/ijfs6030074>
23. Naqvi, S.K., Shahzad, F., Rehman, I.U., Qureshi, F., Laique, U. (2021). Corporate social responsibility performance and information asymmetry: The moderating role of analyst coverage. *Corporate Social Responsibility and Environmental Management*, 28(6), 1549-1563. <https://doi.org/10.1002/csr.2114>
24. Nijman, J., Wei, Y.D. (2020). Urban inequalities in the 21st century economy. *Applied geography*, 117, 102188. <https://doi.org/10.1016/j.apgeog.2020.102188>
25. Oláh, J., Aburumman, N., Popp, J., Khan, M.A., Haddad, H., Kitukutha, N. (2020). Impact of Industry 4.0 on environmental sustainability. *Sustainability*, 12(11), 4674. <https://doi.org/10.3390/su12114674>
26. Ortiz-de-Mandojana, N., Bansal, P. (2016). The long-term benefits of organizational resilience through sustainable business practices. *Strategic management journal*, 37(8), 1615-1631. <https://doi.org/10.1002/smj.2410>
27. Pavone, P., Pagliacci, F., Russo, M., Righi, S., Giorgi, A. (2021). Multidimensional clustering of EU Regions: a contribution to orient public policies in reducing regional disparities. *Social Indicators Research*, 156, 739-759. <https://doi.org/10.1007/s11205-020-02324-9>
28. Pullano, G., Valdano, E., Scarpa, N., Rubrichi, S., Colizza, V. (2020). Evaluating the effect of demographic factors, socioeconomic factors, and risk aversion on mobility during the COVID-19 epidemic in France under lockdown: a population-based study. *The Lancet Digital Health*, 2(12), e638-e649. [http://dx.doi.org/10.1016/S2589-7500\(20\)30243-0](http://dx.doi.org/10.1016/S2589-7500(20)30243-0)
29. Roztocki, N., Soja, P., Weistroffer, H.R. (2020). Enterprise systems in transition economies: research landscape and framework for socioeconomic development. *Information Technology for Development*, 26(1), 1-37. <http://dx.doi.org/10.1080/02681102.2017.1377148>
30. Sánchez, A., Jiménez-Fernández, E. (2023). European Union Cohesion Policy: Socio-economic vulnerability of the regions and the COVID-19 shock. *Applied research in quality of life*, 18(1), 195-228. <https://doi.org/10.1007/s11482-022-10116-1>
31. Sharma, R. (2023). Promoting social inclusion through social policies. *Capacity Building and Youth Empowerment*, 76, 617.
32. Sielker, F., Rauhut, D., Humer, A. (2021). EU Cohesion Policy and European spatial governance: An introduction to territorial, economic and social challenges. In: *EU Cohesion Policy and Spatial Governance* (pp. 1-16). Edward Elgar Publishing. <http://dx.doi.org/10.4337/9781839103582.00008>
33. Stiglitz, J.E. (2016). An agenda for sustainable and inclusive growth for emerging markets. *Journal of Policy Modeling*, 38(4), 693-710. <https://doi.org/10.1016/j.jpolmod.2016.05.012>

34. Suhaeb, F.W., Tamrin, S. (2024). Dynamics of Social Integration in Sustainable Development: A Case Study in Urban Multicultural Societies. *Kurdish Studies*, 12(1), 4102-4111. <https://doi.org/10.58262/ks.v12i1.294>
35. Tai, F.M., Chuang, S.H. (2014). Corporate social responsibility. *Ibusiness*, 6(03), 117. <http://dx.doi.org/10.4236/ib.2014.63013>
36. Tiganasu, R., Lupu, D. (2023). Institutional quality and digitalization: Drivers in accessing European funds at regional level? *Socio-Economic Planning Sciences*, 90, 101738. <https://doi.org/10.1016/j.seps.2023.101738>
37. Tutko, M. (2023). Sustainable development activities in chemical companies in Poland: links between SDGs and ESG. *Zeszyty Naukowe, Organizacja i Zarządzanie [Scientific Papers, Organization & Management]*, 172. Politechnika Śląska [Silesian University of Technology], 599-620. <http://dx.doi.org/10.29119/1641-3466.2023.172.37>
38. Uralovich, K.S., Toshmamatovich, T.U., Kubayevich, K.F., Sapaev, I.B., Saylaubaevna, S.S., Beknazarova, Z.F., Khurramov, A. (2023). A primary factor in sustainable development and environmental sustainability is environmental education. *Caspian Journal of Environmental Sciences*, 21(4), 965-975. <http://dx.doi.org/10.22124/CJES.2023.7104>
39. Valeri, M., Valeri, M. (2019). Sustainable development and corporate social responsibility. *Corporate social responsibility and reporting in sports organizations*, 9-62. http://dx.doi.org/10.1007/978-3-319-97649-5_2
40. Villalba-Eguiluz, U., Egia-Olaizola, A., Pérez de Mendiguren, J.C. (2020). Convergences between the social and solidarity economy and sustainable development goals: Case study in the Basque country. *Sustainability*, 12(13), 5435. <https://doi.org/10.3390/su12135435>
41. Zhong, H., Zhang, J., Song, W. (2023). The relationship between rural information consumption and regional economic development with spatial Durbin model—A case study of Zhejiang, China. *Plos one*, 18(2), e0281405. <https://doi.org/10.1371/journal.pone.0281405>

PREPARING BUSINESS ANALYSTS FOR THE MODERN JOB MARKET: A COMPARATIVE ANALYSIS OF SKILLS AND EDUCATION

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Purpose: To analyse and compare business analytics specializations in bachelor's and engineering programs across selected Polish universities, focusing on the skill sets these programs emphasize to meet market demands.

Design/methodology/approach: The study employed a comparative analysis of curricula across various institutions, organizing courses by primary skill categories: analytical, technical, communication, and project management skills.

Findings: The research highlights distinct differences in focus between bachelor's and engineering programs, with bachelor's programs providing a broader skill base, including essential interpersonal and communication skills, while engineering programs emphasize technical and analytical expertise.

Originality/value: This article provides insights into how business analytics education can be better aligned with market demands, offering a clear breakdown of specialization competencies that may guide curriculum development to address skill gaps in the profession.

Keywords: Business Analytics, Business Analyst Education, Skills Development.

Category of the paper: Research paper.

1. Introduction

In today's rapidly evolving business landscape, the role of a business analyst has become crucial in ensuring that organisations can efficiently adapt to technological advancements and market changes (Min, 2016). Business analysts are responsible for analysing and interpreting data to provide valuable insights, supporting informed decision-making that drives strategic goals. With the growing emphasis on digitalization and data-driven operations, employers increasingly seek skilled professionals capable of navigating complex data environments, anticipating market trends, and optimizing business processes (Bayrak, 2015; Liu et al., 2023).

The business analyst profession has evolved significantly over the past few decades. Traditionally, business analysts were seen as facilitators who helped companies align their technology investments with their business strategies. Their responsibilities included gathering and documenting business requirements, creating process models, and working closely with IT teams to implement technical solutions that addressed specific business challenges (Richards, Marrone, 2014). However, the role of the business analyst has expanded in response to the growing complexity of business environments and the increasing reliance on technology and data to achieve organizational goals.

Studies, such as those by Vashist et al. (2011), highlight how employers are not only looking for professionals who can perform traditional business analysis tasks, such as requirements gathering and process modelling, but are also seeking individuals with advanced technical skills, including proficiency in data visualization tools, programming languages, and predictive analytics. According to Meredith et al. (2019), business analysts have moved beyond their traditional role as intermediaries between business and IT departments and are now expected to contribute to broader strategic initiatives, particularly in areas related to data-driven decision-making and process optimization.

Recent research indicates that business analysts are now seen as strategic partners who can help organizations navigate digital transformation efforts, improve operational efficiency, and gain a competitive advantage through data analysis (Aleryani, 2020). The rising importance of the business analyst in today's market is reflected in employers' growing expectations, which now encompass a wide range of technical, analytical, and soft skills.

This is closely related to digital transformation, which is fundamentally changing the way companies operate. According to Vial (2019), digital transformation refers to the integration of digital technologies into all areas of a business, resulting in fundamental changes to how organizations deliver value to customers. As businesses increasingly adopt digital technologies such as artificial intelligence (AI), machine learning (ML), and the Internet of Things (IoT), the role of the business analyst is evolving to include responsibilities related to the management and implementation of these technologies.

Business analysts are now expected to play a key role in digital transformation initiatives by identifying opportunities for innovation, ensuring that technology implementations align with business objectives, and managing the organizational changes that result from the adoption of new technologies (Mergel et al., 2019). This shift in responsibilities requires business analysts to have a deep understanding of both business processes and digital technologies, as well as the ability to manage change and lead cross-functional teams. According to Richards and Marrone (2014), business analysts who can successfully navigate the challenges of digital transformation are highly valued by employers and are seen as critical to the long-term success of their organizations.

This article conducts a comparative analysis of business analytics specializations within selected bachelor's and engineering programs across Polish universities. It examines the variety and focus of courses within these specializations, categorizing them by the types of skills they aim to develop: analytical, technical, communication, and project management skills. By analyzing data from curricula, the study highlights differences in educational approaches between bachelor's and engineering programs, noting that bachelor's programs generally offer a broader skill set, including interpersonal skills crucial for teamwork. In contrast, engineering programs primarily emphasize technical and analytical competencies. This analysis helps clarify how current educational offerings align with the market demands for business analyst roles.

The research connects educational outcomes to job market demands, such as the growing importance of digital transformation, making it practical and application-oriented. This linkage ensures that educational programs are evaluated not just theoretically but also for their employability outcomes. Another new feature is the division of subjects taught in specializations according to competencies that students can acquire in them. By focusing on the interplay between educational programs and labour market demands in Poland, this article stands out for its localized insights and actionable recommendations.

2. Business Analyst in the Modern Job Market (Example of the Polish Market)

Numerous definitions describe the role of business analytics in shaping organisational value across various industries. However, the most widely accepted neutral definition describes it as a systematic process of transforming raw data into valuable insights (Schniederjans et al., 2014). This is achieved through the application of appropriate techniques, including statistical and quantitative analyses, as well as predictive, mathematical, and optimisation models, all of which can greatly inform sound business decision-making. Business analytics also encompasses the exploration, examination, interpretation, and visualisation of data from diverse sources to identify trends, patterns, and correlations that can drive strategic planning and operational improvements (Wolniak, Grebski, 2023).

Over the years, interest in data analysis has been growing, with new areas emerging, such as Big Data and business analytics, as shown in Figure 1.

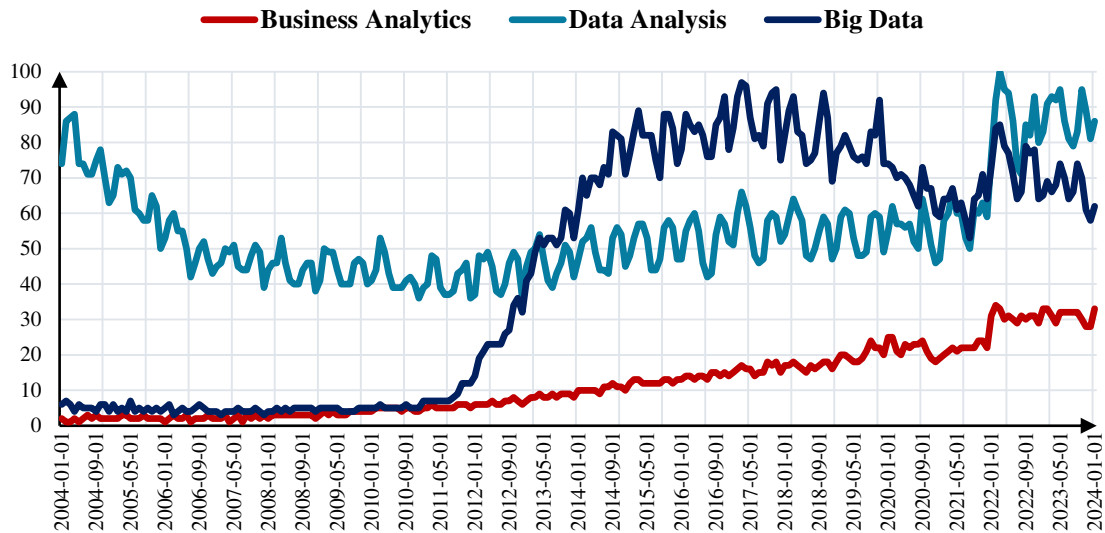


Figure 1. Interest in key terms related to business analytics from 2004 to 2024.

Source: own study based on the Google Trends platform (2024).

Employers are increasingly investing in the development of analytical teams in their companies, which leads to the employment of more and more business analysts. According to research conducted by the U.S. Bureau of Labor Statistics (2024), the demand for these specialists is growing yearly. It is expected to increase by 11% from 2023 to 2033, much faster than the average for all professions. Similar trends are observed in Poland. Similar trends are observed in Poland. Just Join IT analysis indicates that in 2022, business analysts (especially in the IT industry) could count on 2.5 times more job offers in 2022 than a year earlier and on pay rises of around 17% (Marszycki, 2023).

This data is also confirmed by the latest report 'The Future of Education. Scenarios 2046', which was developed by the Infuture Institute and Collegium da Vinci (The Future of Education. Scenarios 2046, 2021). It indicates that data analysis is one of the five key competences of the future, which will enjoy growing interest in the coming years.

In addition, according to research conducted by Coders Lab (2021), which aimed to check the popularity of other professions not related to programming in the IT industry, the profession of business analyst came first. Among the job advertisements that appeared from January to June 2021 on the Pracuj.pl website, 6,143 concerned the position of business analyst. The exact distribution of these offers by voivodeship is presented in Figure 2. As can be seen in Figure 2, the vast majority of offers belong to companies located in the Mazowieckie Voivodeship.

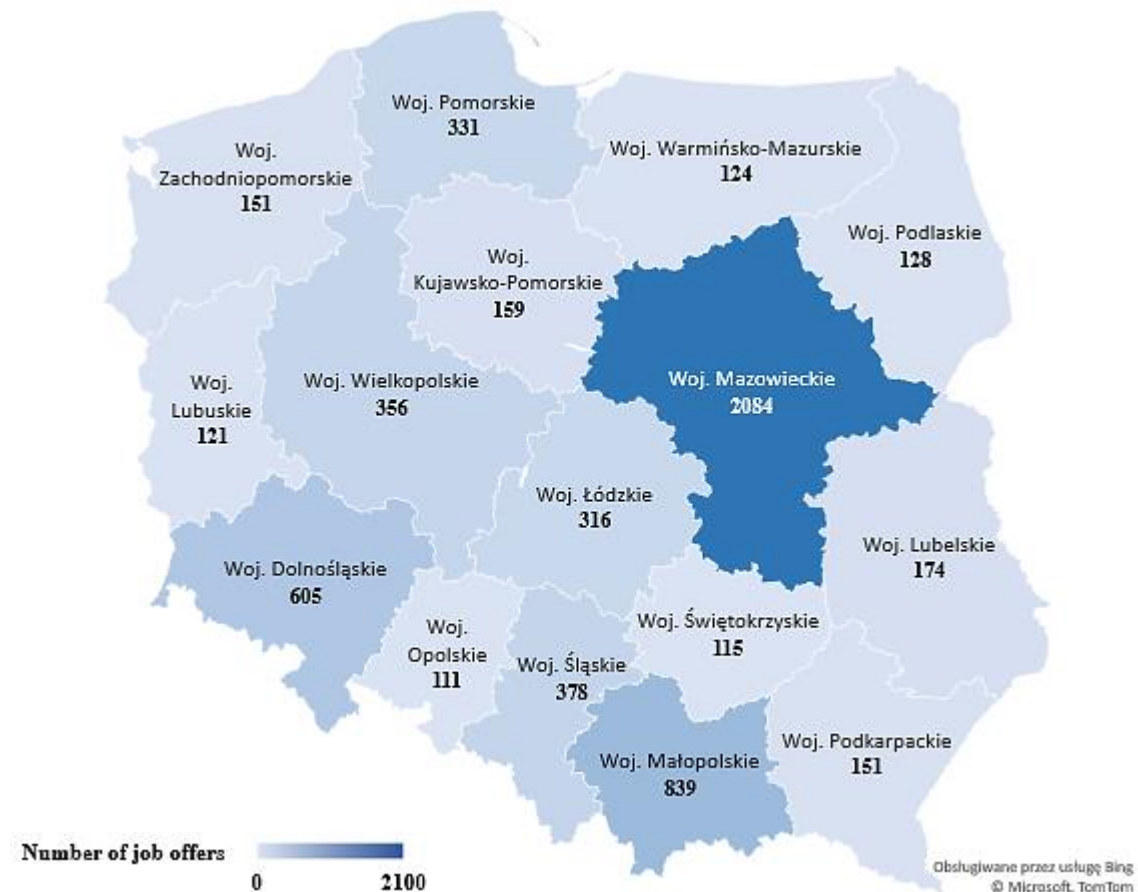


Figure 2. Number of job offers for business analysts in Poland, broken down by voivodeship, from January to June 2021.

Source: own study based on Coders Lab (2021)

It should also be noted that the popularity of the business analyst profession is also associated with high earnings, as shown in Table 1. The data was obtained from the wynagrodzenia.pl website, which was last updated in January 2024 (Wynagrodzenia.pl, 2024).

Table 1.
Gross salary distribution by job level for business analyst

	Amounts in Polish zloty		
	Q ₁	Me	Q ₃
Junior Specialist	5 680	6 760	8 010
Specialist	7 770	9 570	12 000
Senior Specialist	9 750	12 610	16 110

Source: own study based on wynagrodzenia.pl website <https://wynagrodzenia.pl/moja-placa/ile-zarabia-analytik-biznesowy>

An analysis of data from the National Salary Survey (Table 1) reveals that salaries for analyst positions vary significantly based on competencies and level of professional experience. Notably, for specialist roles, the first quartile exceeds the average gross salary set by the President of the Central Statistical Office, which was PLN 715,548 in 2023. Additionally, 25% of junior specialists earn at least PLN 8010, highlighting the high profitability and financial attractiveness of this profession.

To better understand the role of a business analyst, it is essential to define their function within an organisation's operations and outline the competencies and skills required for success in this field. According to the authors of the PMI Guide to Business Analysis from the Project Management Institute, a business analyst acts as a bridge between stakeholders, responsible for gathering and examining data derived from business performance assessments. This role also involves refining and shaping expectations related to products and other information necessary for building a shared understanding of the product's applications across the entire team (The PMI Guide to Business Analysis, 2018). Such a professional makes decisions based on factual data, which consistently feeds into the company's knowledge base. The actions of a business analyst significantly impact various business areas, reinforcing their operations. Therefore, a business analyst must possess both technical and soft skills that enable them to fulfil their duties effectively.

As Shah (2017) emphasizes, one of the most important tasks of a business analyst is to ensure the appropriate flow of information between business and project teams and teams dealing with IT tasks. The key role of a business analyst in IT and business processes, who often acts as a link between business and technology departments in organizations, is also noted by Paul (2018). His main tasks include: collecting and analysing requirements, designing solutions, supporting the testing and implementation process of new systems and solutions, and analysing and optimizing processes in the organization. Each of these tasks requires a business analyst to have a wide range of skills, including communication skills, the ability to work with diverse teams, and a solid understanding of both the business and technology context, making him or her an important player in the implementation of organizational projects and initiatives. In performing their duties, analysts very often use various tools and programs for data analysis and visualization. Their use helps in better communication between business analysts and stakeholders. According to the annual survey conducted by Bulldogjob Think IT (2024), the most commonly used tools by analysts include programs such as Microsoft Excel, Python, Microsoft Power BI, Tableau, Oracle, Microsoft SQL Server, Enterprise Architect.

In summary, it can be concluded that business analysts should possess competencies and skills that can be categorized into the following main areas:

- **Analytical skills** (logical thinking, problem analysis, identifying patterns and trends in data, understanding statistical models, forecasting, and modelling techniques that help predict future events based on historical data).
- **Communication skills** (teamwork, time management, adaptability to rapidly changing conditions, the ability to communicate complex analysis results understandable, and the skill of creating clear reports and presentations).
- **Technical skills** (data management and analysis capabilities, proficiency with tools that enable the processing of large datasets and deriving valuable insights).
- **Project management skills** (overseeing the lifecycle of an analytical project, from problem identification through data collection and analysis to implementing recommendations).

3. Research Methods

The article employs a comparative analysis methodology to evaluate business analytics educational programs in bachelor's and engineering degrees across selected Polish universities. This method was chosen because it enables a systematic examination of differences and similarities in curricula and their alignment with labour market demands. Moreover, it facilitates identifying trends, strengths, and weaknesses in educational approaches to prepare business analysts. This approach is consistent with the article's goal of examining how educational offerings match market needs.

The data sources were the syllabi from official university websites and course catalogues. These are primary sources of information, ensuring accuracy and relevance in the analysis of educational content. Each subject included in the study programmes was assigned skills that students could acquire by completing these courses. Since the study programs contain a huge number of subjects (several dozen), the research was narrowed down to subjects taught within the specializations related to data analysis.

Skills were grouped into four categories—analytical, technical, communication, and project management. This classification reflects the competencies expected of modern business analysts, as identified in industry reports and literature (e.g., PMI Guide to Business Analysis). It ensures the study's findings are directly applicable to workforce requirements. Five bachelor's degree programs and five engineering degree programs from leading Polish universities were selected for the analysis, including Silesian University of Technology, Warsaw School of Economics, University of Economics in Katowice, University of Szczecin, Adam Mickiewicz University in Poznań, Wrocław University of Science and Technology, Cracow University of Technology, Lodz University of Technology and Kielce University of Technology.

In addition, the analysis results were correlated with labour market data (e.g., wage reports and labour demand statistics). The source of this data were platforms such as wynagrodzenia.pl and Google Trends, as well as IT market reports. This ensures that the analysis is based on real-world relevance, linking education to industry.

4. Results and Discussion

In light of the mentioned forecasts and the current job market situation, significant changes have also taken place in Polish universities in recent years. Many institutions have expanded their educational offerings, creating new programs focused on data analysis or updating existing study tracks to better align students' skills with current market needs. As a result, an increasing number of individuals now have the opportunity to gain the qualifications necessary to pursue careers as business analysts.

According to information available on the Forbes portal, obtaining employment as a business analyst generally requires at least a bachelor's degree (Tompkins, 2023). In Poland, this level of higher education includes both bachelor's and engineering studies, which differ in duration and the degree awarded. A bachelor's program typically spans at least six semesters and concludes with a bachelor's degree. In contrast, engineering programs are slightly longer, lasting at least seven semesters, or approximately three and a half years, and lead to a professional title with engineering competencies.

The study programs offered by Polish higher education institutions that provide education in business analytics at both the bachelor's and engineering levels were analysed. Given the extensive number of courses within these programs, the analysis focused specifically on courses offered in data analysis-related specializations. Table 2 outlines the courses available in these specializations at selected universities and within bachelor's degree programs. These courses were aligned with specific competencies and skills that can be acquired through their completion, according to the categories identified in the previous chapter: AS - analytical skills, TS - technical skills, CK - communication skills, and PMS - project management skills.

Table 2.

Courses taught within specializations for selected bachelor's degree programs, categorized by competency areas

University Name	Subject Name	Skill Type
Silesian University of Technology (PS) Field of Study: Business Analytics Specialisation: Data and Business Process Analysis	Time Series Analysis and Forecasting	AS
	Market Data Analysis	AS
	Project Management in Economic Data Analysis	AS, PMS
	Market and Competition Theories	AS
	Financial Reporting of Enterprises	AS, TS
	Business Process Analytics	AS, TS
	Financial Investment Design	AS
	Public Sector Financial Management	AS, PMS
	Socioeconomic Process Simulation	AS, TS
	Enterprise Risk Management Systems	AS
	Derivatives Market	AS
	Basics of Sustainable Development	AS
	Knowledge Engineering and Expert Systems	TS
	Corruption Risk Prevention in Organizations	AS
	Game Theory	AS
	Intercultural Communication and Elements of Business Psychology	CK
	Technological Process Control	TS
University of Economics in Katowice (UE Katowice) Field of Study: Informatics and Econometrics Specialisation: Data Analytics	Decision Support Systems	AS
	Data Processing, Analysis, and Visualization in SAS	TS
	Data Integration and Processing in Analytical Systems	TS
	Structural Data Analysis	AS
	Regression Models	AS
	Risk Analysis and Management	AS
	Business Data Visualization	CK
	Business Intelligence Engineering	TS
	Data Warehouse Engineering	TS
	Knowledge Discovery Process Engineering	AS, TS

Cont. table 2.

University of Szczecin (USZ) Field of Study: Informatics and Econometrics Specialisation: IT Business Analyst	Data Warehouses	TS
	User Requirements Engineering	TS, CK
	Business Analytics Methods	AS
	Data Mining Methods in Behavioural Economics	AS
	Artificial Intelligence Methods in Business Analysis	TS
	Machine Learning Methods	TS, AS
	Process Modelling in Business Analysis	AS
	Business Intelligence Systems	TS
	IT Systems in Economic Records	TS
	Business Decision Support Systems	AS
	Database Management Systems	TS
	Advanced-Data Analysis Methods	AS
	IT Security Management	AS
	Knowledge Resources in IT Systems	TS
Warsaw School of Economics (SGH) Field of Study: Quantitative Methods in Economics and Information Systems Specialisation: Data Analysis	Labor Market Research and Analysis Methods	AS
	Microdata in Demographic and Economic Process Analysis	AS
	Statistics in Business	AS
	Visualisation and Reporting of Statistical Analyses	CK
	Introduction to Actuarial Statistics	AS
Adam Mickiewicz University in Poznań (UAM) Field of Study: Mathematics Specialisation: Statistics and Data Analysis	Probability Calculus	AS
	Data Processing and Visualization	TS
	Mathematical Statistics	AS
	Algebra	AS
	Discrete Mathematics	AS
	Measure and Integral Theory	AS
	Topology and its Applications	AS

Source: own study.

The data presented in Table 2 indicates that the highest number of courses is offered within the Data and Business Process Analysis specialization of the Business Analytics program at the Silesian University of Technology, totalling 17 courses. In contrast, the lowest number of courses (5) is found in the Data Analysis specialization within the Quantitative Methods in Economics and Information Systems program at the Warsaw School of Economics. It is important to note that these courses are exclusive to each specialization, meaning the overall number of courses for each program is significantly higher. Courses related to thesis seminars and internships are not included in Table 2.

Based on the data in Table 2, Figure 3 was created to provide a more comprehensive view of the number of courses within each specialization that develop the highlighted competencies and skills. The data presented in Figure 3 show that the most diverse educational offer in terms of subjects taught is the specialization in Data and Business Process Analysis in the Business Analytics major (Silesian University of Technology). It is the only one that offers classes that allow you to gain skills and competencies in all the distinguished areas (AS - analytical skills, TS - technical skills, CK - communication skills, and PMS - project management skills).

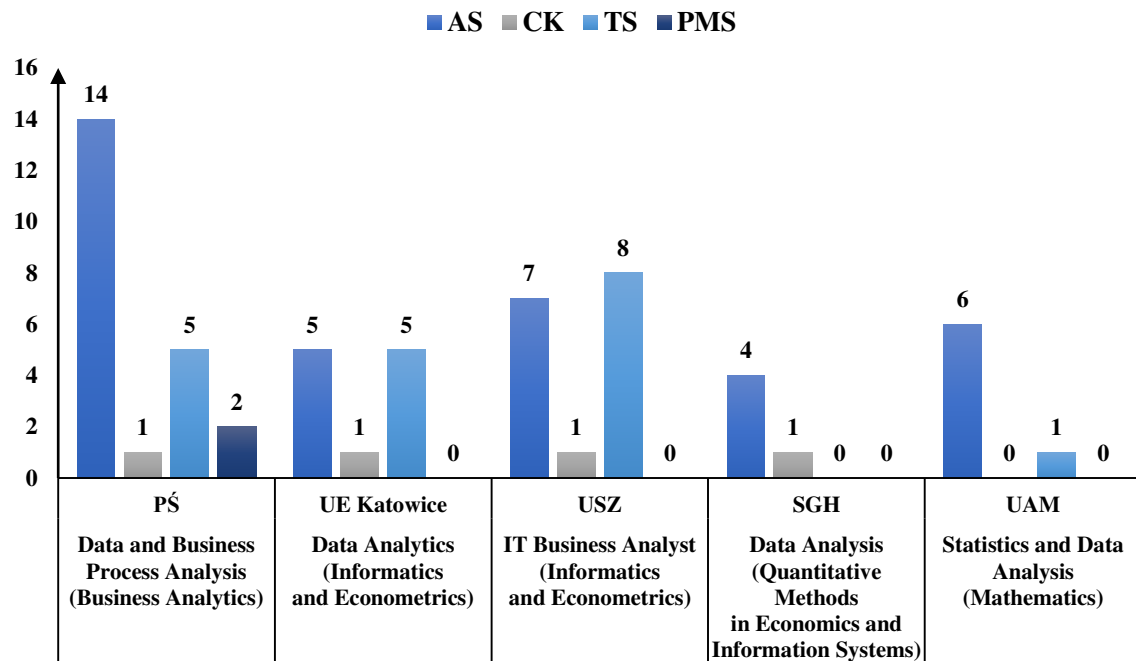


Figure 3. Courses in specializations for selected universities and bachelor's programs by skill type.

Source: own study.

In the case of the Computer Science and Econometrics major, where the specializations Data Analytics (University of Economics in Katowice) and IT Business Analyst (University of Szczecin) are available, it can be seen that both universities focus on developing similar competencies in their students and through a similar number of courses, taking into account both analytical, technical and communication competences (Fig. 3). On the other hand, the majors offered by SGH and UAM have the fewest courses in specializations and focus mainly on analytical competences.

An analysis of the skills students can acquire through their studies was also conducted for engineering programs. Data for selected engineering study programs are presented in Table 3.

Table 3.

Courses taught within specializations for selected engineering degree programs, categorized by competency areas

University Name	Subject Name	Skill Type
Wrocław University of Science and Technology (PWR) Field of Study: Mathematics Specialisation: Machine Learning and Data Engineering	Survival Analysis	AS
	Regression Models and Their Applications	AS
	Survey Data Analysis	AS
	Time Series Analysis	AS
	Financial Market Modelling	AS
	Monte Carlo Methods	AS, TS
	Representation Methods	AS
	Nonparametric Methods	AS

Cont. table 3.

Cracow University of Technology (PK) Field of Study: Applied Mathematics Specialisation: Data Analytics	Applied Algebra	AS
	Data Analysis	AS
	Physics Laboratory	TS
	Algorithms and Computational Complexity	AS, TS
	Databases	TS
	Introduction to Artificial Intelligence	TS
	Regression and Analysis of Variance	AS
	Advanced Numerical Methods	TS
	Machine Learning	AS, TS
	Large Data Set Processing	TS
	Discrete Dynamic Systems	AS
	Optimisation Theory	AS, TS
	Signal Analysis	TS
	Algebraic Coding	TS
	Mathematics in Computer Graphics	TS
	Information Theory	AS
	Geometry	AS
	Basics of Cryptography and Cryptanalysis	TS
	Introduction to Quantum Computing	AS, TS
	Knot Theory	AS
Lodz University of Technology (PL) Field of Study: Applied Computer Science Specialisation: Software Engineering and Data Analysis	Database Administration and Programming	TS
	Applications in Interpreted Languages	TS
	Metaheuristics and Their Applications	AS
	Cloud Computing Systems	TS
	Spatial Data Analysis	AS
	Introduction to Mobile Systems	TS
	Programming in Python	TS
	Project-Oriented Programming	TS
	Software Engineering	TS
	Computer Recognition Systems	AS, TS
	Problem Workshop in Software Engineering	PMS
	Intelligent Data Analysis Techniques	AS, TS
	Business Intelligence Tool Design	TS
	Network Database Systems	TS
	Advanced Java Programming	TS
	Quality in Software Production Processes	TS
	Internet Marketing	TS
	Optimisation Methods in Economics	AS
	Digital Signal Processing	TS
Silesian University of Technology (PŚ) Field of Study: Computer Science Specialisation: Data Analysis Engineering	Data Visualisation and Processing	TS
	Statistical Data Analysis	AS
	Data Mining Algorithms	AS, TS
	Cloud Computing, Big Data, and Social Media	TS
Kielce University of Technology (PŚk) Field of Study: Data Engineering Specialisation: Data Analytics and Modelling	Fundamentals of Programming in a Computer-Based Analytical Environment	TS
	Discovering Relationships in Multidimensional Data	AS
	Selected Models of Classification and Regression	AS
	Unstructured Data Analysis	AS, TS

Source: own study.

Based on the data in Table 2, the specializations of Data Analytics in Applied Mathematics at the Cracow University of Technology and Software Engineering and Data Analysis in Applied Computer Science at the Lodz University of Technology have the highest number of courses, with 20 courses offered in each. In contrast, the lowest number of courses is found in the Data Analysis Engineering specialization within Computer Science at the Silesian University of Technology and the Data Analytics specialization in Data Engineering at the Kielce University of Technology, each offering only 4 courses. As mentioned earlier, these are only courses offered within the specialization, not the entire degree program.

Using the data from Table 3, Figure 4 was created to provide a more comprehensive view of the number of courses within each specialization, categorized by the competencies acquired. The information presented above (Fig. 4) indicates that, among the specializations for selected engineering programs and universities, there is less variation in teaching methods compared to bachelor's level programs. These specializations primarily focus on developing technical and analytical skills. Communication skills are not developed in any of the analysed specialisations, and project management skills are only offered by the Lodz University of Technology in the specialisation of Software Engineering and Data Analysis.

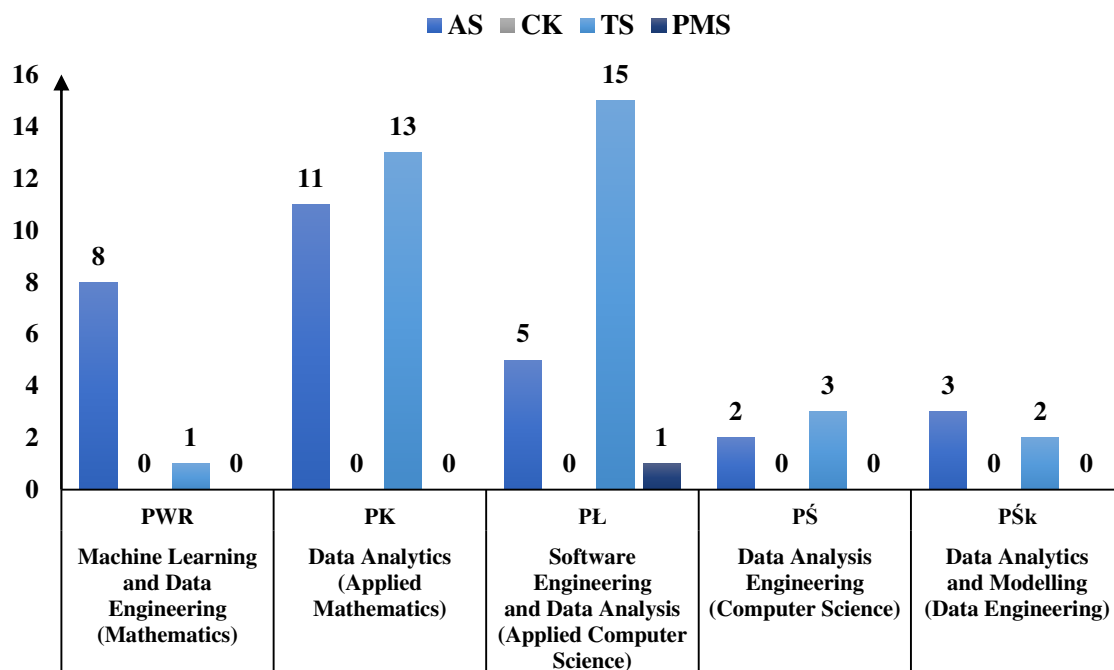


Figure 4. Courses in specializations for selected engineering degree programs by skill type.

Source: own study.

The information regarding the analysed skills for the selected specializations in both bachelor's and engineering programs is consolidated in Figure 5. Analysing the data in Figure 5 reveals clear differences between the curricula of bachelor's and engineering programs. Bachelor's programs tend to focus on providing a comprehensive skill set, encompassing both foundational data analysis skills using advanced analytical tools and essential social competencies that are crucial for effective collaboration with other teams.

Engineering programs, on the other hand, are primarily focused on developing technical skills among students, complemented by courses that also build analytical abilities. However, there may be a noticeable gap due to the limited number of courses aimed at enhancing interpersonal competencies.

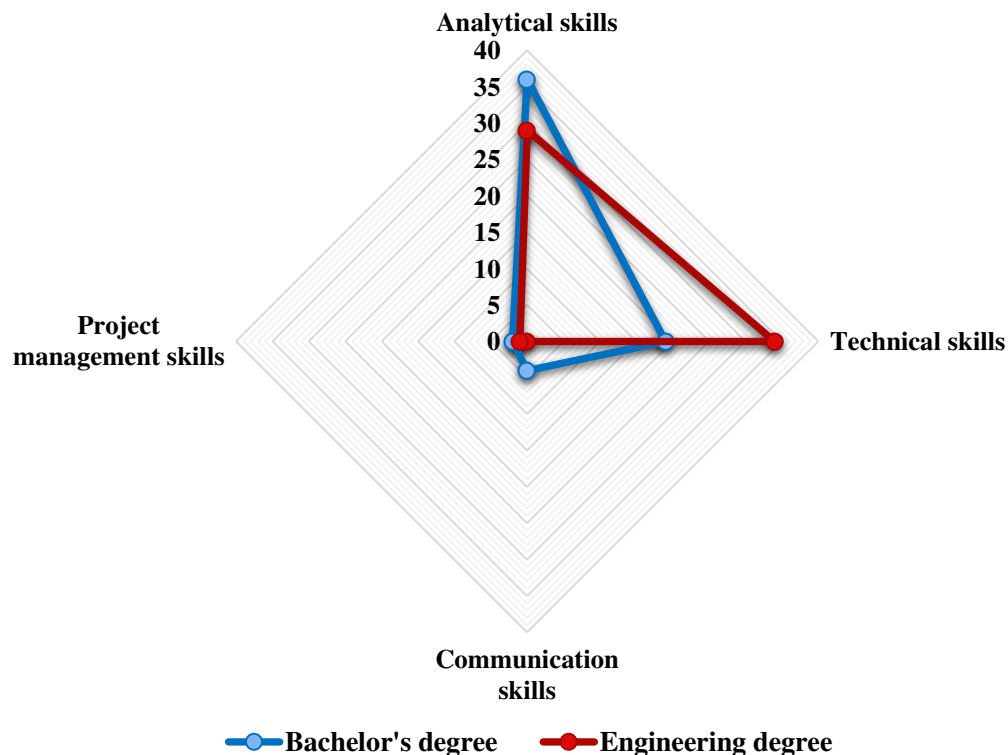


Figure 5. Comparative analysis of business analytics specializations by skill groups for selected bachelor's and engineering study programs.

Source: own study.

The findings of this study provide significant insights into the current state of business analytics education in Poland, bridging the gap between academic offerings and labour market demands. Below, we discuss the implications of our results, the novelty of our analyses, and their broader significance.

Our research highlights clear distinctions between bachelor's and engineering programs in preparing business analysts for the job market. Bachelor's programs tend to offer a more comprehensive skill set, encompassing both technical and interpersonal competencies, whereas engineering programs are more focused on technical and analytical skills. This delineation reflects how these programs align with different professional expectations: bachelor's graduates are better equipped for roles requiring collaboration and communication, while engineering graduates are more suited for technically demanding positions.

These results underscore the importance of tailoring educational strategies to meet evolving industry requirements. As businesses increasingly integrate advanced technologies such as artificial intelligence, machine learning, and big data, the need for a diversified skill set among

business analysts becomes critical (Liu et al., 2023). Our analysis suggests that curricula should strive for a balance between technical expertise and interpersonal skills to meet these demands effectively, while previous studies have highlighted mainly the importance of technical and analytical skills in business analytics (Popoola et al., 2024; Farayola et al., 2023).

Our research categorizes and compares specific courses offered by Polish universities. This provides a granular understanding of how educational programs contribute to the development of specific competencies.

By correlating educational outcomes with labour market trends, our study emphasizes the direct applicability of skills taught in business analytics programs. Previous research has often focused solely on labour market needs (Kumar, 2019; Meredith et al., 2019; Hilarowicz et al., 2023). We don't find research on curriculum specific to business analysts. our approach integrates both approaches, we analyse study programs and market needs in the field of business analysts.

5. Conclusion

In this study, we have examined the educational pathways and skill requirements for business analysts, with a specific focus on business analytics programs at Polish universities. The findings highlight notable differences in how bachelor's and engineering programs prepare students for the demands of the business analyst role. Bachelor's programs generally emphasize a well-rounded skill set, including analytical, communication, and project management skills, which are critical for effective teamwork and stakeholder interaction. In contrast, engineering programs focus more intensively on technical and analytical skills, aligning with the specialized needs of technical roles in the industry.

Our analysis underscores that business analysts today are expected to possess a diverse range of competencies, from logical and statistical analysis to advanced technical proficiency and interpersonal skills, which is also emphasized by Farayola et al. (2023) and Popoola et al. (2024). These requirements reflect the role's evolution from a support function to a strategic position instrumental in guiding organizations through digital transformation and data-driven decision-making. As businesses increasingly integrate technologies like artificial intelligence and machine learning, the ability to bridge technical understanding with business objectives becomes paramount. This blend of skills enables analysts not only to interpret complex data but also to drive insights that support organizational growth and competitiveness.

This article can serve as a valuable guide for universities looking to align their curricula with the evolving needs of the business analytics market. By highlighting the specific competencies sought by employers, this study provides insights into how academic programs can adapt to the needs of the labour market.

The study focuses exclusively on Polish universities. The analyses conducted concerned curricula and secondary data from the labour market but did not include direct employer input. Therefore, our future plans include investigating how the skills acquired by graduates translate into professional success and long-term adaptation to the labour market. We also plan to compare the Polish educational offer with that in other Central and Eastern European countries to identify regional trends and opportunities for improvement and also analyse job offers for business analysts.

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References

1. Aleryani, A. (2020). A data analysis perspective by the Business Analyst and Data Scientist. *International Journal of Scientific and Research Publications*, 10(9), pp. 234-243.
2. Bayrak, T. (2015). A Review of Business Analytics: A Business Enabler or Another Passing Fad. *Procedia-Soc. Behav. Sci.*, 195, pp. 230-239.
3. Bulldogjob Think IT (2024). *IT Community Research Report 2024 IT Analysts*. Retrieved from: <https://bulldogjob.pl/it-report/2024/analitik-it>
4. Coders Lab (2021). *Report from The IT industry is not just about programmers*. Retrieved from: https://coderslab.pl/pl/baza-wiedzy#branza_IT.
5. Farayola, O.A., Abdul, A.A., Irabor, B.O., Okeleke, E.C. (2023). Innovative business models driven by AI technologies: a review. *Computer Science & IT Research Journal*, 4(2), pp. 85-110.
6. Farayola, O.A., Adaga, E.M., Egieya, Z.E., Ewuga, S.K., Abdul, A.A., Abrahams, T.O. (2024). Advancements in predictive analytics: A philosophical and practical overview. *World Journal of Advanced Research and Reviews*, 21(3), pp. 240-252.
7. Google Trends platform (2024). <https://trends.google.com/trends/explore?date=2004-01-01%202024-01-01&q=big%20data,business%20analytics,data%20analysis&hl=pl>
8. Hilarowicz, A.B., Zielosko, M., Myśliwiec, M.A. (2023). The Employers' Expectations Towards Students' Competencies In The Framework Of Digital Transformation Processes. *Procedia Computer Science*, 225, pp. 4521-4530.

9. Kumar, M. (2019). The New Age Business Analyst: Managing Business Analysis for Agile Development. *ARISCOM Journal of Management*, 1(1), pp. 62-67.
10. Liu, S., Liu, O., Chen, J. (2023). A Review on Business Analytics: Definitions, Techniques, Applications and Challenges. *Mathematics*, 11, 899.
11. Marszycki, M. (2023). *The demand for IT analysts and their salaries are growing*. ITwiz. Retrieved from: <https://itwiz.pl/rosnie-popyt-na-analitykow-it-oraz-ich-zarobki/>
12. Meredith, P., Summons, P., Park, M., Cheek, B. (2019). What do Employers expect from Business Analysts and is it captured by the “Business Analysis Body of Knowledge” (BABOK)? ACIS 2019. *Proceedings*, 93.
13. Mergel, I., Edelman, N., Haug, N. (2019). Defining digital transformation: Results from expert interviews. *Government Information Quarterly*, 36(4).
14. Min, H. (2016). *Global Business Analytics Models: Concepts and Applications in Predictive, Healthcare, Supply Chain, and Finance Analytics*. Pearson FT Press.
15. Paul, D. (2018). *Defining the role of the business analyst: The Business Analysis Service Framework*. Henley Business School, The University of Reading.
16. Popoola, O.A., Adama, H.E., Okeke, C.D., Akinoso, A.E. (2024). The strategic value of business analysts in enhancing organizational efficiency and operations. *International Journal of Management & Entrepreneurship Research*, 6(4).
17. Richards, D., Marrone, M. (2014). Identifying the Education Needs of the Business Analyst: An Australian Study. *Australasian Journal of Information Systems*, 18(2), pp. 165-186.
18. Schniederjans, M.J., Schniederjans, D.G., Starkey, C.M. (2014). *Business Analytics Principles, Concepts, and Applications with SAS: What, Why, and How*. New Jersey: Pearson Education, Inc.
19. Shah, M. (2017). Evolving Role of a Business Analyst. *International Journal of Business and Management*, 1(2), pp. 7-12.
20. *The Future of Education. Scenarios 2046* (2021). Report developed by the Infuture Institute and Collegium da Vinci, <https://infuture.institute/raporty/przyszlosc-edukacji/>, October 18, 2024.
21. *The PMI Guide to Business Analysis* (2018). Newtown Square, Pennsylvania: Project Management Institute.
22. Tompkins, J., *How To Become A Business Analyst: A Step-By-Step Guide*. V. Beagle (ed.), <https://www.forbes.com/>, 30 maj 2023.
23. Vashist, R., McKay, J., Marshall, P. (2011). *Reflecting on use of practice theories to understand ‘practices’: a boundary practice perspective on work of business analysts*. Conference: International and Interdisciplinary Workshop on Practice Research, pp. 1-14.
24. Vial, G. (2019). Understanding digital transformation: A review and a research agenda. *The Journal of Strategic Information Systems*, 28(2), pp. 118-144.

25. Wolniak, R., Grebski, W. (2023). The Concept of Diagnostic Analytics. *Scientific Papers of Silesian University of Technology Organization and Management Series*, 175, pp. 651-669.
26. Wynagrodzenia.pl (2024). *How much does a business analyst earn?* Retrieved from: <https://wynagrodzenia.pl/moja-placa/ile-zarabia-analitek-biznesowy>

SHAPING GREEN COMPETENCES OF TRANSPORT AND LOGISTICS EMPLOYEES THROUGH GREEN ACTIVITIES

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Purpose: The aim of this research is to identify the directions for shaping green competences in entities within the transport and logistics industry operating in the Polish market, through the implementation of various types of green activities.

Design/methodology/approach: The study was planned and conducted between September 2024 and November 2024. A total of 7149 Environmental, Social, and Governance (ESG) practices implemented between 2016 and 2023 in entities operating within the Polish market were analysed. Of these, 330 ESG practices were identified as directly related to the transport and logistics industry. The descriptions of these identified ESG practices were subsequently analysed using the author's approach, which focuses on examining green activities implemented in business entities and their role in shaping green competences.

Findings: Ninety-two green practices from the transport and logistics industry were identified, based on their attribution to at least one of the eleven identified green activities. The analysis revealed that various types of green practices are being implemented in transport and logistics entities, which can contribute to the shaping of employees' green competences.

Research limitations/implications: A limiting factor of the study was the selection of a database containing case studies, which was restricted to the ESG practices database on the website of the Forum Odpowiedzialnego Biznesu in Poland. However, this limitation ensured the homogeneity of the descriptions of the analysed ESG practices within the transport and logistics industry in the context of sustainability issues. Furthermore, this approach enables the

possibility of repeating the research in the future, extending it to cover additional periods for comparative purposes, provided that the data are available.

Originality/value: This study distinguishes itself from other research in this field by focusing on the analysis of shaping green competences within the transport and logistics industry through the implementation of various types of green activities. Additionally, six dimensions of green competence are highlighted, including green knowledge, green skills, green behaviour, green attitudes, green abilities, and green awareness. Promising future research avenues in this area could include exploring the role and significance of green practices and related green activities in the transport and logistics industry, particularly concerning the quality of green jobs created or the emergence and functioning of green supply chains. This article is intended for those interested in issues related to the shaping of green competences in the transport and logistics industry.

Keywords: green competences, green economy, green jobs, green logistics, green supply chain, sustainable development.

Category of the paper: Research paper.

1. Introduction

Sustainability has become a significant topic in numerous academic discussions concerning the transport and logistics industry. This body of research can be categorised into purely theoretical studies, practical applications, or a combination of both. Regardless of the classification, it is important to emphasise that researchers in this field aim to identify the role and significance, or even determine the impact, of implementing sustainability principles on the overall functioning of the transport and logistics industry, as well as on the activities of the individual economic actors within it (e.g. Ayadi et al., 2024; Fareed et al., 2024; Nicoletti, Appolloni, 2024). Consequently, in addition to focusing on further economic development, there is a growing emphasis on analysing the interactions between individual economic actors in the transport and logistics industry and the environment. Simultaneously, these studies are situated within a narrower or broader social and business context.

Through the lens of existing research, the authors of this article recognise that the implementation of sustainable development within individual entities in the transport and logistics industry is a complex and multidimensional process. Furthermore, for this process to be truly sustainable, it must be integrated with the existing value system of the organisation, alongside the values derived from the concept of sustainable development. Therefore, taking one-off or sporadic actions towards sustainability will not yield significant benefits or lasting changes necessary for transforming an organisation towards sustainability.

Some of the practices implemented by actors in the transport and logistics industry may contribute to placing them on a sustainable or even greener path (e.g. Beškovnik, Twrdy, 2012; Evangelista, 2014; Vienažindienė et al., 2021). Practices that produce such effects are referred to as sustainable practices (e.g. Ahmad et al., 2024; Andrei et al., 2024), green solutions

(e.g. Pham, N.D.K. et al., 2023), or simply green practices (e.g. Gupta, Singh, 2020; Layaoen et al., 2024; Rosano et al., 2022). However, it is not possible to pinpoint exactly when the greening of the transport and logistics industry will occur, although references to green logistics (e.g. Piva, 2024; Tetteh et al., 2024) or green transport (e.g. Mubarak et al., 2024; Shah et al., 2021) can already be found in some academic discussions. These studies often focus on specific case studies or simply reference green logistics and/or green transport as key directions of change arising from the implementation of sustainable development, particularly the ongoing green transformation of the economy. One notable aspect of this transformation in the transport and logistics industry, which can be observed and studied in individual actors, is the issue of shaping green competence.

The aim of the research presented in this article is to identify the directions for shaping green competences in entities within the transport and logistics industry operating on the Polish market through the implementation of various types of green activities. To achieve this research objective, descriptions of Environmental, Social, and Governance (ESG) practices from 2016 to 2023, implemented by entities in the transport and logistics industry on the Polish market and available in the Responsible Business Forum database, were subjected to scientific analysis. The study conducted qualitative analyses of these ESG practice descriptions, using a structured and pre-prepared tool designed to identify the green actions undertaken within each practice. Based on the identified green actions, further inferences were drawn regarding the directions of green competence shaping among employees in the transport and logistics industry. The data obtained were visualised using the VOSviewer software (version 1.6.20), demonstrating a broader application of this tool than is typically seen in its traditional use for presenting bibliometric data on analysed scientific publications.

The article is divided into five interrelated sections. The first section provides a general introduction to the area of analysis. In addition to highlighting the issue of sustainability and the green transformation occurring in the transport and logistics industry, it also presents the aim of the research and outlines the methods used. The second section offers a literature review focused on green competence and explores the six dimensions of these specific competences. The methodological aspects briefly introduced in the first section are developed and discussed in detail in the third section of the article. A key element of this section is the detailed presentation of the timeline for the analyses undertaken, as well as the procedure for selecting appropriate case studies characterised by green actions. The results, along with the associated discussion, are presented in the penultimate section. This discussion is enriched with suggestions for future research directions in the field. In the concluding part of the research discussion, the authors emphasise that the issue of shaping green competences among employees in the transport and logistics industry is not only an important area for future research but also a significant challenge for managers in this sector, particularly in light of the ongoing green transformation of the economy.

2. Literature review

Research on the issue of green competence cites various definitions of the concept (Olekanma et al., 2024; Sulich, Kozar, 2024). These definitions differ on the one hand, in the approach of individual authors to the question of distinguishing green competences, and on the other hand, in the specifics of the context analysed. Hence, it is worth noting, for example, that Subramanian et al. (2016), in the context of green human resource management, emphasise that green competences are the requisite ecological knowledge, skills and other socioeconomic behavior an individual has to help him/her behave and act rightly and responsibly toward the overall well-being of his/her immediate environment. On the other hand, the research by Cabral & Dhar (2019) indicates that an organisation needs to develop green competencies among human resources (employees/managers) to reduce the harmful impact on the natural environment. Kozar (2017) reaches similar conclusions in research focused on green jobs, highlighting that green competences of employees are the result of their knowledge and skills in applying pro-environmental solutions in the company. The diversity of approaches to research on green competences has led some scholars to attempt to divide them into natural green competencies and acquired green competencies (e.g. Pham, D.D.T., Paillé, 2019; Shoaib et al., 2021; Subramanian et al., 2016). At the same time, various researchers increasingly point out that the concept of green competences is still evolving, both in theory and in practice (Cabral, Dhar, 2021). As a result, comparing individual studies aimed at understanding the role and importance of green competences in the green transformation of the economy proves to be challenging.

The scientific discourse to date on the issue of green competence has increasingly focused on isolating the individual constituent dimensions of such specific competences. As a result, numerous scholarly reflections now indicate that green competence is a multidimensional construct encompassing six distinct dimensions (e.g. Abdelkareem et al., 2024; Cabral, Dhar, 2019; Yafi et al., 2021). These include green skills (e.g. Nurcholis et al., 2024), green behaviour (e.g. Farooq et al., 2022; Mirčetić et al., 2022), green attitudes (e.g. Gull, Idrees, 2022; Joshi, 2022; Liu et al., 2022), green abilities (e.g. Sudolska, 2022; Sudolska, Łapińska, 2023), and green awareness (e.g. Kozar, Sulich, 2023; Prasetyo et al., 2024). Such targeted research, as recognised by the authors of this article, is important from the perspective of business practice, as it can contribute to increased efficiency in the process of shaping green competence. The desired effect can be achieved through the targeted shaping of green competences in relation to a selected dimension or dimensions.

The issue of green competence is discussed in academic discourse in relation to various topics concerning both transport and logistics. For example, the shaping of green competence is explored in the context of implementing effective and efficient reverse logistics (Lee, Lam, 2012; López-Morales et al., 2015), as well as the role of green competence in the creation of

green supply chains (Burki et al., 2019; Kozar et al., 2024). It is also highlighted that the possession of green competencies by employees is crucial for the effective implementation of green supply chain management processes (Murad, Zou, 2024). The various dimensions of green competence mentioned above are also a key component of diverse academic considerations involving transport and/or logistics issues (e.g. Kozar et al., 2024; Leung et al., 2023; Polinori et al., 2018).

3. Research methodology

The study was planned and conducted between September and November 2024. The research activities undertaken, as outlined in the research schedule presented in Figure 1, were divided into four distinct stages. All research activities were carefully designed to facilitate a thorough, step-by-step analysis aimed at achieving the stated research aim. Consequently, it is not possible to identify any one research activity as more important than the others listed. These activities should, therefore, be regarded as equally significant in the process of obtaining the research results presented later in this article.

The first stage of the research focused on identifying the current research problem within the context of the transport and logistics industry. To this end, a review of scientific publications was conducted using the Google Scholar search engine, along with the Scopus and Web of Science databases. A search across these three databases, which contain bibliographic descriptions of scientific publications from various academic fields, revealed that issues related to the gradual green transformation of the economy are increasingly being addressed within the field of transport and logistics. In this context, the question of shaping employees' green competences occupies a central role. Based on the review, the authors of this article identified two key research issues. First, the process of shaping green competences is complex and multidimensional, due to the specific nature of the transport and logistics industry. Second, the shaping of green competences among employees in this sector can occur through the implementation of various sustainable development practices in the daily operations of transport and logistics entities. It was observed that some of these targeted practices are even referred to as green practices. Although the issue of shaping green competences in the transport and logistics industry has been addressed in the literature, this remains a relatively new and important area of scientific inquiry. In the authors' view, this area will continue to evolve in the coming years, both from the perspective of further research and from a practical standpoint, particularly in relation to the development and implementation of various sustainable or green practices.

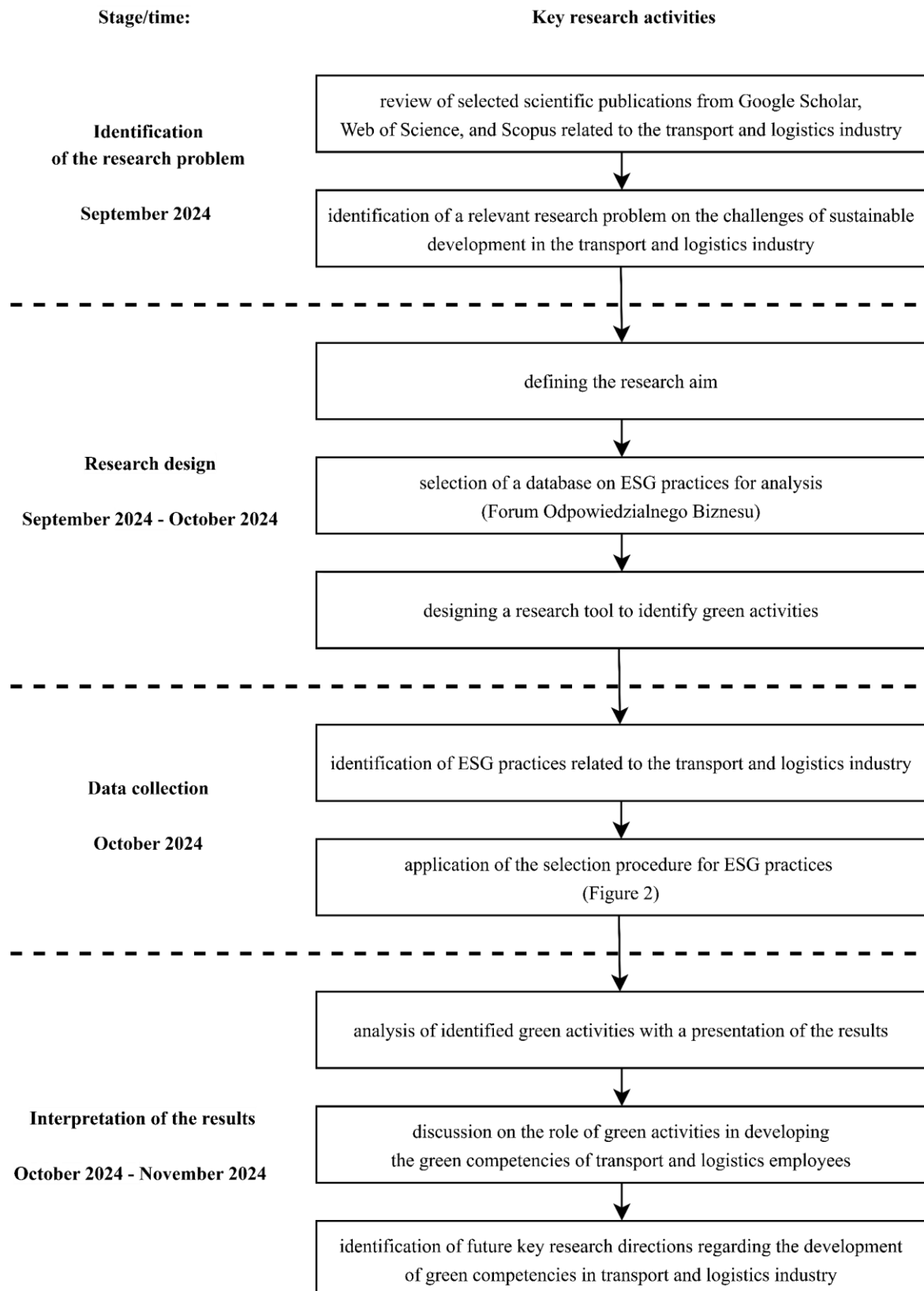


Figure 1. Stages of the research procedure and timeline.

Source: Authors' elaboration.

Conclusions from the first stage of the research and the availability of research material contributed to the development of key research assumptions, including the formulation of the research aim. Thus, it was determined that the aim of the research would be to identify the directions of shaping green competences in entities from the transport and logistics industry operating on the Polish market through the implementation of various types of green activities. The Forum Odpowiedzialnego Biznesu database, which contains descriptions of ESG practices from various industries (including transport and logistics), was selected for analysis due to its data collection period and the consistent manner in which the information is recorded. The best practices listed in this database underwent a selection process, which is also illustrated in Figure 2. In addition to identifying ESG practices within the transport and logistics industry, a screening process was carried out, which included an assessment of the consistency in recording all selected practices (the requirement to attribute at least one sustainable development goal, as outlined in Agenda 2030, within the database) and verification based on the presence of a green action. It was assumed that a given practice would be classified as a green practice if the solutions or practices implemented as a result of it contribute to reducing the negative impacts of economic activity on the environment. At the same time, in the interest of standardization and the replicability of future scientific inquiries, it was established that a green practice would occur when the implemented activities are consciously aimed at:

- reducing or eliminating plastic waste (A),
- rationalising water consumption (B),
- a reduction in the carbon footprint and overall reduction in air pollution through the improvement of individual processes within the business entity (C),
- the increased efficiency and more rational use of electricity (D),
- introducing solutions to enable or increase the use of energy from renewable sources in the energy mix (E),
- preserving biodiversity and actively promoting environmental protection and the creation of green spaces (F),
- segregation, recycling, or upcycling of waste (G),
- promoting greener commuting choices to and from the workplace (H),
- reduction of paper consumption (I),
- environmental education (J),
- zero waste policy and various types of collections aimed at exchange (K).

The criteria adopted and indicated above have made it possible to identify from among all the ESG practices collected in the Forum Odpowiedzialnego Biznesu database those that are simultaneously assigned to the transport and logistics industry and are characterised by the fact that they can be called green practices (green activities are implemented as part of them).

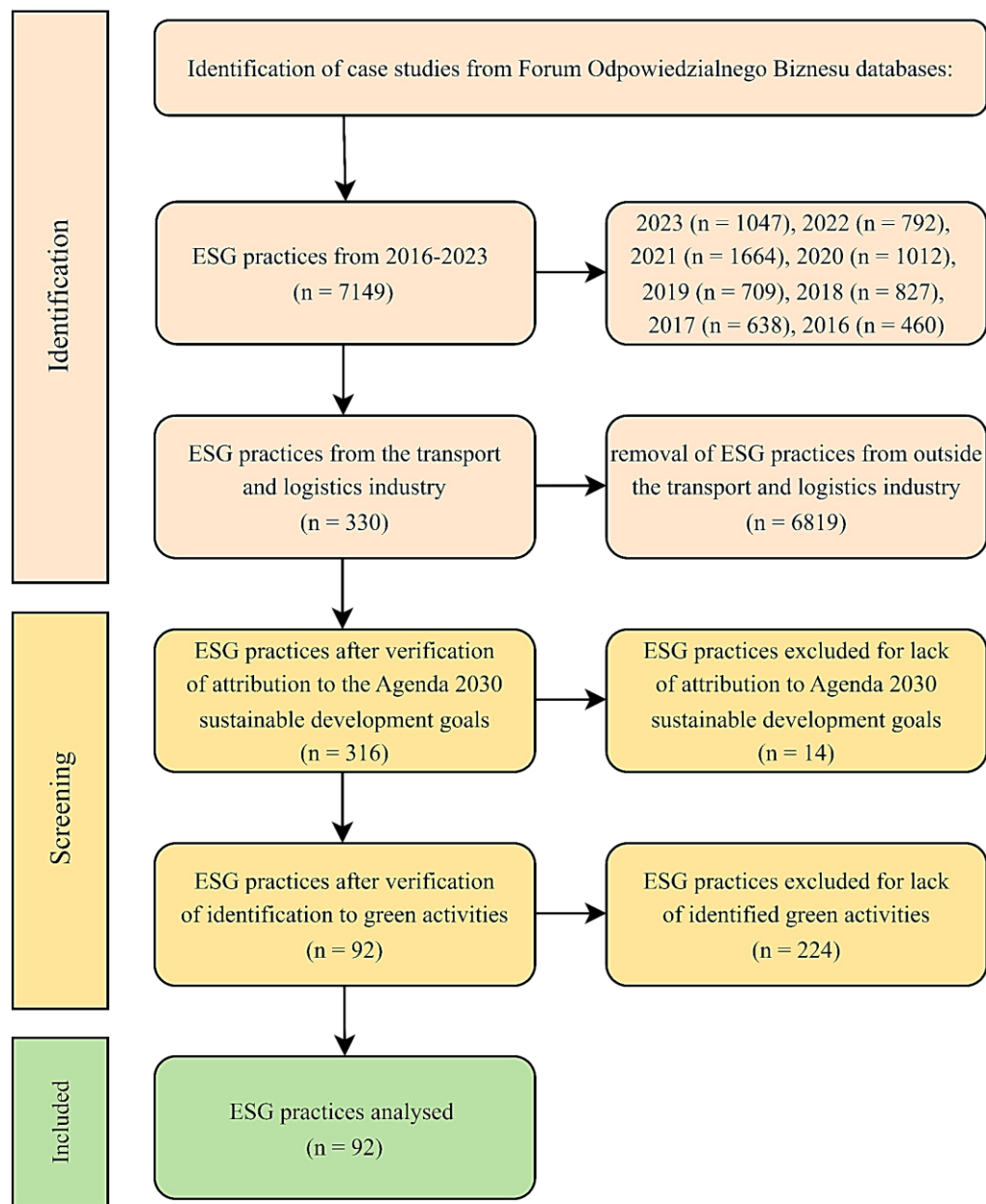


Figure 2. Research procedure for identifying ESG practices (green practices) for the study.

Source: Authors' elaboration.

The final stage of the research focused on analysing the results obtained from the examination of the 92 green practices identified in the transport and logistics industry. A detailed description of this stage, along with a discussion, is provided in the following part of the article. However, at this point, it is important to highlight the limitations of the study. The primary limitation lies in the selection of the ESG case study database that was analysed. Therefore, the results presented should be interpreted solely within the context of this database and cannot be generalised to sustainable or green practices in the transport and logistics industry in Poland as a whole. Another notable limitation is the author's approach to identifying green practices within the broader category of sustainable practices. These limitations, however, do not diminish the value of the analyses, as they demonstrate how green practices can be

distinguished from sustainable practices and how their role in shaping green competencies can be defined. Consequently, the analyses presented can serve as a valuable reference for other researchers who either employ different methods for extracting green practices or use entirely different ESG practice databases within the transport and logistics industry (including those based on the authors' own research). The methodology for identifying green activities can also be applied to studies of other economic sectors.

4. Results and discussion

A database of 92 identified ESG practices, for which at least one green activity was found to be in progress, and which could contribute to shaping the green competencies of employees, was created and analysed using VOSviewer software. This program is typically used to present bibliometric data across various fields, including those related to transport (e.g. Bao et al., 2023; Vengadesh et al., 2023), logistics (e.g. Nikseresht et al., 2024; Salas-Navarro et al., 2024; Vincek et al., 2023), and sustainable development (e.g. Wodnicka, Królikiewicz, 2024). However, the application of this software is much broader and also allows for the visualisation of data from qualitative analyses after appropriate aggregation. Thus, during the analysis of ESG practices, as indicated in the methodological section of this article, practices from the transport and logistics industry were assessed to determine whether any of the eleven measures were implemented that could indicate their "greenness". These individual measures, ranging from A to K, were assigned letters of the alphabet, which also facilitated clear visualisation of the data using VOSviewer software. The analysis conducted in this way aimed to visually map all the implemented measures that contributed to a practice being classified as green.

To generate a map visualising the co-occurrence of implemented green activities, the co-occurrence analysis panel selected co-occurrence (as the analysis type), full counting (as the counting method), and set the minimum number of occurrences of a keyword (in this case, activities A to K) to 1. This indicator value allowed the creation of a bibliometric map displaying all the implemented green activities, of which there were 187 in total across the 92 analysed practices. This also highlights that some of the green practices featured more than one implemented activity (Figure 3). It is also important to note that each area identified on the map, representing the visualisation of co-occurring green activities, is labelled in two ways and assigned exclusively to one of the two automatically generated clusters (either the red or green cluster). Each area is first identified by the letter corresponding to the activity in question (from A to K). Additionally, red or green dots of varying sizes can be seen, with the size of the dot reflecting the number of practices in which the activity was implemented (the larger the dot, the more green practices incorporated that activity).



Figure 3. Network visualization of co-occurring green activities shaping green competences.

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

To deepen the analysis, for each of the identified implemented green actions visualised in Figure 3, figures indicating occurrences and links were generated using VOSviewer software. These measures are shown in Table 1 in brackets next to each of the green actions labelled from A to K. The first measure in each bracket, links (L), represents the number of implemented green actions, as shown in the visualisation of the network of links, with which a given green action co-occurred at least once across all the analysed green practices. These connections are represented by the lines extending from each individual green action depicted. Since eleven green actions were analysed in the study, the maximum number of links could be 10. The second measure, occurrences (O), listed in Table 1, indicates the number of green practices in which a given green action was implemented. The maximum possible number of occurrences in the study could have been 92, reflecting the total number of green practices identified. However, no green action occurred in all of the identified green practices.

The research conducted showed that green activities C (red cluster), D (red cluster), and G (red cluster) were the only ones that co-occurred at least once in the analysed practices with all other green activities studied. These activities were characterised by specific measures or technological changes implemented within organisations, aimed at minimising the negative environmental impact of the respective economic entity. Simultaneously, these activities focused on changing employees' pro-environmental behaviour and raising their awareness in this regard. As a result, they were primarily targeted at shaping green behaviour and green awareness. In contrast, the most frequently referenced green activity in the analysed practices was the green J-action (green cluster). Environmental education contributes to shaping the

green knowledge of individual employees working in the transport and logistics industry. Additionally, such targeted measures can be implemented to a greater extent by a larger number of actors, compared to the implementation of often costly organisational or technological changes, such as those aimed at introducing green innovations in these areas.

Table 1.

Green activities co-occurrence clusters displayed in Figure 3

Cluster	Color	Keywords
1	red	A (L = 6, O = 7); B (L = 9, O = 12); C (L = 10, O = 32); D (L = 10, O = 21); E (L = 8, O = 11); G (L = 10, O = 14)
2	green	F (L = 9, O = 17); H (L = 9, O = 14); I (L = 8, O = 9); J (L = 9, O = 42); K (L = 8, O = 8)

green action

aimed at:

A reducing or eliminating plastic waste

B rationalising water consumption

C a reduction in the carbon footprint and overall reduction in air pollution through the improvement of individual processes within the business entity

D the increased efficiency and more rational use of electricity

E introducing solutions to enable or increase the use of energy from renewable sources in the energy mix

F preserving biodiversity and actively promoting environmental protection and the creation of green spaces

G segregation, recycling, or upcycling of waste

H promoting greener commuting choices to and from the workplace

I reduction of paper consumption

J environmental education

K zero waste policy and various types of collections aimed at exchange

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

The analyses carried out showed that green competences were shaped by different types of green actions implemented in individual green practices. In more than 55% of the green practices, two or more green activities implemented were identified, as shown in Figure 4. At the same time, it should be noted that in most of these cases two different activities were implemented simultaneously through a given green practice. In one of the analysed practices, eight different green activities were identified, which at the same time represents the highest number of such activities implemented simultaneously through a single practice. The multidirectional shaping of green competences through different green activities should be considered very important, as it can contribute to building different dimensions of such specific competences.

Through the prism of the analysed green practices and the green actions identified within their scope, the authors of this article observed that green competences can be shaped both directly and indirectly. In the case of direct shaping of green competences, employees actively participate in a given green activity (they may be its initiator and/or participant). In contrast, with indirect shaping of green competences, employees are not actively involved in the implementation of a given green action (they are merely observers of the results and are aware of the entity's sustainable, or less frequently green, orientation where they are employed). Given this distinction in how green competences can be shaped, the authors suggest that managers in transport and logistics entities should focus on maximising practices aimed at

directly shaping green competences. Direct involvement of employees in the implementation of a given green action, in the authors' view, can help consolidate relevant green patterns of attitudes and behaviours, thereby fostering a sense of ownership over these actions. In cases where employees are only observers of green changes, which are not actively communicated to them, even with appropriate training, the formation of green competences may not occur. In such situations, employees may view the changes as alien, incomprehensible, or external, hindering the internalisation of green practices.

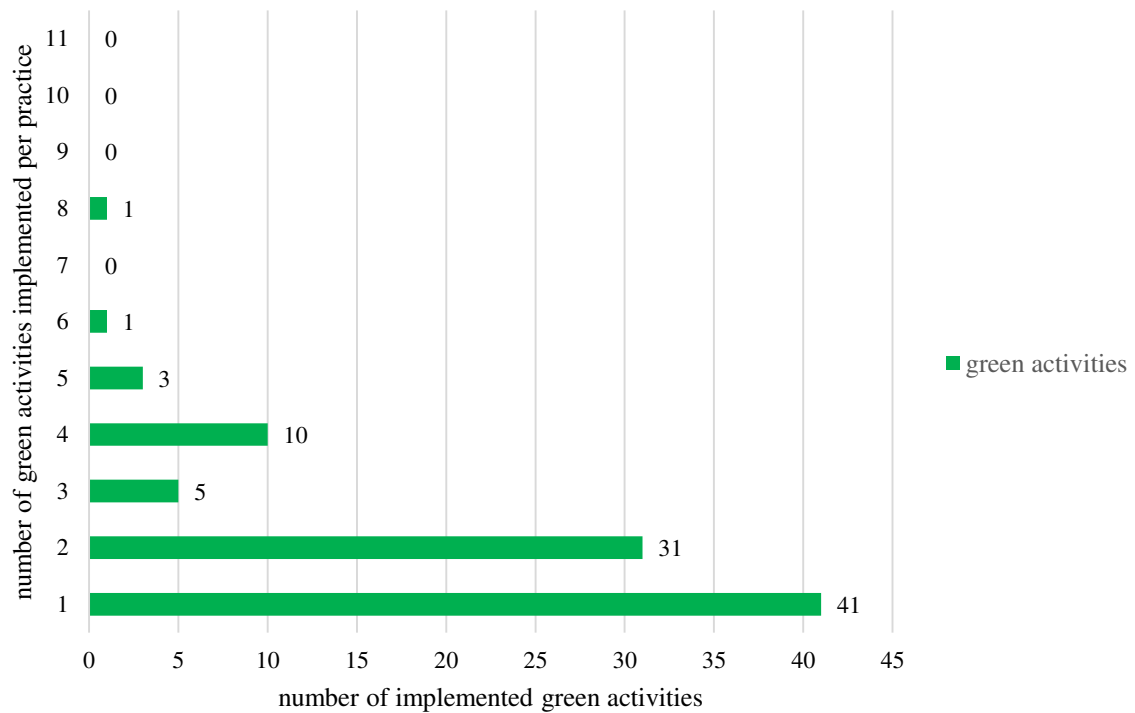


Figure 4. Number of green activities aimed at shaping green competences within a single green practice. Source: Authors' elaboration.

In terms of the green measures implemented in individual entities, it is evident that there is still insufficient emphasis on initiatives aimed at reducing or eliminating plastic waste, adopting a zero waste policy, and implementing various types of collections for replacement, as well as measures to reduce paper and water consumption. In the opinion of the authors of this article, those responsible for shaping the green competences of employees should focus on such practices, which, while not necessarily spectacular in the media, can gradually change employees' environmental behaviour and, most importantly, can be easily introduced within individual organisations, often without incurring additional costs.

The green measures identified in this study are discussed in various types of research, including studies in industries outside of transport and logistics, which focus on the development of green knowledge, green skills, green behaviour, green attitudes, green abilities, and green awareness. At the same time, it should be noted that the implementation of some of the green measures observed in this study depends on factors external to the organisation.

These include the availability of new technologies, such as innovative green technologies (e.g. Kharb et al., 2024; Wang et al., 2022), and the availability of adequate infrastructure, such as a well-developed public transport system that supports greener commuting choices. Therefore, in order to effectively shape some of the green attitudes, it is essential for managers in individual transport and logistics companies to collaborate with decision-makers who influence the development of public transport in their areas. Only through such collaboration can intelligent and sustainable transport systems be achieved, which are increasingly the focus of scientific discourse. For instance, issues related to sustainable transport solutions in urban areas (e.g. Bhellar et al., 2023; Podgórnjak-Krzykacz, Przywojska, 2023) or the development of public bicycle systems (e.g. Frade et al., 2022; Podgórnjak-Krzykacz et al., 2022; Torres et al., 2024) are actively being discussed. In this context, it should be noted that the green measure aimed at promoting greener commuting choices includes not only carpooling but also encouraging employees to use public transport more frequently or to choose a bicycle instead of a car.

Developing solutions aimed at shaping green competence is undoubtedly a critical challenge for managers of transport and logistics operators, who are already grappling with the gradual green transformation of the economy. For instance, there is a noticeable increase in environmental awareness among consumers, leading to the emergence of a new category of consumers, often referred to as green consumers (e.g. Borah et al., 2024; Young et al., 2010). As the authors of this article acknowledge, these consumers expect green services of adequate quality from the transport and logistics industry. Consequently, future research should focus on identifying which green competences should be developed among transport and logistics professionals, particularly in light of the growing importance of the green consumer. This consumer not only considers the characteristics of the goods they purchase but also the manner in which these goods are delivered.

From the perspective of future research, a qualitative assessment of the green competences of workers in the transport and logistics industry should also be conducted. This study should be approached from multiple perspectives, including those of managers, employees, and consumers. Additionally, it would be valuable to explore whether the development of green competences among employees leads to the creation of green jobs in the transport and logistics industry, and if so, to what extent.

Another important area for future research on shaping green competences in the transport and logistics industry should focus on measuring the so-called green competence gap. The issue of the green competence gap and how to measure it is already being explored in the literature (Nikoloski et al., 2024; Pavlova, 2018). Therefore, it is becoming increasingly crucial to develop appropriate measurement tools that are both easy to apply and cost-effective for individual business entities. This would enable transport and logistics operators to effectively manage their employees, consciously shape their green competences, and mitigate the negative impact of the green competence gap on the functioning of the green supply chain.

5. Summary

The study presented here differs from previous research in that it starts by identifying green practices and the green actions associated with them as the foundation for discussing the shaping of green competences. Furthermore, the use of VOSviewer software to analyse the co-occurrence of green actions within green practices allowed for a more comprehensive understanding of the complexity of this issue.

The study identified eleven green activities that can shape various dimensions of green competence. A particular emphasis was placed on the positive impact of direct employee involvement in individual green activities on the development of green competences. Additionally, it was noted that environmental education continues to play a significant role in shaping these competences. However, the authors believe that managers of transport and logistics operators should consider implementing training programs tailored to each generation, as this would enhance their effectiveness. Furthermore, modern training techniques, including the use of gamification, should be incorporated more frequently to improve knowledge delivery.

As indicated, the green transformation of the economy, which is gradually taking place, is becoming a challenge for those responsible for the management of entities in the various sectors of the economy. Thus, the development of research aimed at identifying the role and importance of shaping green competences on the functioning of the transport and logistics industry should be considered inevitable. However, it is already possible to point out that the direction of green in the transport and logistics industry will imply the necessity to continuously improve the level of green competences held by employees in order to follow the expectations of, for example, increasingly green-oriented consumers.

References

1. Abdelkareem, R.S., Mady, K., Lebda, S.E., Elmantawy, E.S. (2024). The effect of green competencies and values on carbon footprint on sustainable performance in healthcare sector. *Cleaner and Responsible Consumption*, 12, 100179. <https://doi.org/10.1016/j.clrc.2024.100179>
2. Ahmad, M., Jida, Z., Ul Haq, I., Tufail, M., Saud, S. (2024). Linking green transportation and technology, and environmental taxes for transport carbon emissions. *Transportation Research Part D: Transport and Environment*, 136, 104450. <https://doi.org/10.1016/j.trd.2024.104450>
3. Andrei, N., Scarlat, C., Ioanid, A. (2024). Transforming E-Commerce Logistics: Sustainable Practices through Autonomous Maritime and Last-Mile Transportation Solutions. *Logistics*, 8(3), 71. <https://doi.org/10.3390/logistics8030071>

4. Ayadi, H., Benaissa, M., Hamani, N., Kermad, L. (2024). Assessing the Sustainability of Transport Systems through Indexes: A State-of-the-Art Review. *Sustainability*, 16(4), 1455. <https://doi.org/10.3390/su16041455>
5. Bao, L., Kusadokoro, M., Chitose, A., Chen, C. (2023). Development of socially sustainable transport research: A bibliometric and visualization analysis. *Travel Behaviour and Society*, 30, 60-73. <https://doi.org/10.1016/j.tbs.2022.08.012>
6. Beškovnik, B., Twrdy, E. (2012). Green logistics strategy for South East Europe: To improve intermodality and establish green transport corridors. *Transport*, 27(1), 25-33. <https://doi.org/10.3846/16484142.2012.663731>
7. Bhellar, M.G., Talpur, M.A.H., Khahro, S.H., Ali, T.H., Javed, Y. (2023). Visualizing Travel Accessibility in a Congested City Center: A GIS-Based Isochrone Model and Trip Rate Analysis Considering Sustainable Transportation Solutions. *Sustainability*, 15(23), 16499. <https://doi.org/10.3390/su152316499>
8. Borah, P.S., Dogbe, C.S.K., Marwa, N. (2024). Generation Z's green purchase behavior: Do green consumer knowledge, consumer social responsibility, green advertising, and green consumer trust matter for sustainable development? *Business Strategy and the Environment*, 33(5), 4530-4546. <https://doi.org/10.1002/bse.3714>
9. Burki, U., Ersoy, P., Najam, U. (2019). Top Management, Green Innovations, and the Mediating Effect of Customer Cooperation in Green Supply Chains. *Sustainability*, 11(4), 1031. <https://doi.org/10.3390/su11041031>
10. Cabral, C., Dhar, R.L. (2019). Green competencies: Construct development and measurement validation. *Journal of Cleaner Production*, 235, 887-900. <https://doi.org/10.1016/j.jclepro.2019.07.014>
11. Cabral, C., Dhar, R.L. (2021). Green competencies: insights and recommendations from a systematic literature review. *Benchmarking: An International Journal*, 28(1), 66-105. <https://doi.org/10.1108/BIJ-11-2019-0489>
12. Evangelista, P. (2014). Environmental sustainability practices in the transport and logistics service industry: An exploratory case study investigation. *Research in Transportation Business & Management*, 12, 63-72. <https://doi.org/10.1016/j.rtbm.2014.10.002>
13. Fareed, A.G., De Felice, F., Forcina, A., Petrillo, A. (2024). Role and applications of advanced digital technologies in achieving sustainability in multimodal logistics operations: A systematic literature review. *Sustainable Futures*, 8, 100278. <https://doi.org/10.1016/j.sftr.2024.100278>
14. Farooq, K., Yusliza, M.Y., Muhammad, Z., Mat, N.H.N. (2022). Make it their Decisions, not your Directives: Exploring Required Green Competencies for Employee Ecological Behaviour. *Organizacija*, 55(2), 128-141. <https://doi.org/10.2478/orga-2022-0009>
15. Frade, I., Ribeiro, A., Dias, D., Tchepele, O. (2022). Bike sharing systems implementation impact on emissions, for cyclist preferred routes in urban areas. *International Journal of Sustainable Transportation*, 16(10), 901-909. <https://doi.org/10.1080/15568318.2021.1949076>

16. Gull, S., Idrees, H. (2022). Green training and organizational efficiency: mediating role of green competencies. *European Journal of Training and Development*, 46(1/2), 105-119. <https://doi.org/10.1108/EJTD-10-2020-0147>
17. Gupta, A., Singh, R.K. (2020). Managing operations by a logistics company for sustainable service quality: Indian perspective. *Management of Environmental Quality: An International Journal*, 31(5), 1309-1327. <https://doi.org/10.1108/MEQ-11-2019-0246>
18. Joshi, G. (2022). Green Employability: Re-Shaping Individual Career Perspective. *Sustainable Development Goals Series: Vol. Part F2737* (pp. 7-25). Springer. https://doi.org/10.1007/978-3-031-06558-3_2
19. Kharb, R., Saini, N., Kumar, D. (2024). Driving environmental sustainability in emerging economies: The nexus of green finance, foreign direct investment, financial development, and green technology innovation. *Business Strategy and Development*, 7(4). <https://doi.org/10.1002/bsd2.70008>
20. Kozar, Ł. (2017). Shaping the Green Competence of Employees in an Economy Aimed at Sustainable Development. *Green Human Resource Management (Zielone Zarządzanie Zasobami Ludzkimi)*, 6(119), 55-67.
21. Kozar, Ł.J., Sulich, A. (2023). The Development of Employees' Green Competencies Through Sustainable Business Practices. *Forum Scientiae Oeconomia*, 11(3), 127-143. https://doi.org/10.23762/FSO_VOL11_NO3_7
22. Kozar, Ł.J., Wodnicka, M., Chomicz, G., Jaksik, D.P., Śmietana, K.S. (2024). Green supply chain and green logistics: a bibliometric identification of key research areas. *Zeszyty Naukowe Politechniki Śląskiej. Organizacja i Zarządzanie*, 203, 189-207. <https://doi.org/http://dx.doi.org/10.29119/1641-3466.2024.203.11>
23. Layaoen, H.D., Abareshi, A., Abdulrahman, M.D.-A., Abbasi, B. (2024). Impacts of institutional pressures and internal abilities on green performance of transport and logistics companies. *The International Journal of Logistics Management*, 35(6), 2087-2113. <https://doi.org/10.1108/IJLM-09-2023-0382>
24. Lee, C.K.M., Lam, J.S.L. (2012). Managing reverse logistics to enhance sustainability of industrial marketing. *Industrial Marketing Management*, 41(4), 589-598. <https://doi.org/10.1016/j.indmarman.2012.04.006>
25. Leung, T.C.H., Guan, J., Lau, Y.-Y. (2023). Exploring environmental sustainability and green management practices: evidence from logistics service providers. *Sustainability Accounting, Management and Policy Journal*, 14(3), 461-489. <https://doi.org/10.1108/SAMPJ-03-2022-0133>
26. Liu, J., Gao, X., Cao, Y., Mushtaq, N., Chen, J., Wan, L. (2022). Catalytic Effect of Green Human Resource Practices on Sustainable Development Goals: Can Individual Values Moderate an Empirical Validation in a Developing Economy? *Sustainability*, 14(21), 14502. <https://doi.org/10.3390/su142114502>
27. López-Morales, V., Ouzrout, Y., Manakitsirisuthi, T., Bouras, A. (2015). MKMSIS: A Multi-agent Knowledge Management System for Industrial Sustainability. *Studies in*

- Computational Intelligence*, Vol. 607. Cham: Springer, pp. 195-213. https://doi.org/10.1007/978-3-319-19833-0_9
28. Mirčetić, V., Ivanović, T., Knežević, S., Arsić, V.B., Obradović, T., Karabašević, D., Vukotić, S., Brzaković, T., Adamović, M., Milojević, S., Milašinović, M., Mitrović, A., Špiler, M. (2022). The Innovative Human Resource Management Framework: Impact of Green Competencies on Organisational Performance. *Sustainability*, 14(5), 2713. <https://doi.org/10.3390/su14052713>
 29. Mubarak, H., Aziz, A., Juandi, J., Wijayanto, G. (2024). Environmentally Friendly Sustainable Green Transportation: Ecological, Economic and Social Dimensions. *Civil Engineering and Architecture*, 12(4), 2970-2982. <https://doi.org/10.13189/cea.2024.120434>
 30. Murad, M., Zou, S. (2024). Untangling the influence of green human capital on green supply chain management practices through environmental education and internal environmental management. *International Journal of Innovation Science*, 16(5), 855-876. <https://doi.org/10.1108/IJIS-01-2023-0026>
 31. Nicoletti, B., Appolloni, A. (2024). Green Logistics 5.0: a review of sustainability-oriented innovation with foundation models in logistics. *European Journal of Innovation Management*. <https://doi.org/10.1108/EJIM-07-2024-0787>
 32. Nikoloski, D., Sulich, A., Sołoducho-Pelc, L., Mancheski, G., Angelski, M., Petkoska, M. M. (2024). Identifying green skills gaps through labor market intelligence. *Journal of Infrastructure, Policy and Development*, 8(6), 4868. <https://doi.org/10.24294/jipd.v8i6.4868>
 33. Nikseresht, A., Golmohammadi, D., Zandieh, M. (2024). Sustainable green logistics and remanufacturing: a bibliometric analysis and future research directions. *International Journal of Logistics Management*, Vol. 35, Issue 3. Emerald Publishing, pp. 755-803 <https://doi.org/10.1108/IJLM-03-2023-0085>
 34. Nurcholis, G., Supriyono, B., Hakim, L., Hermawan, R. (2024). Green Competencies in Shipping Industry: Construct Development and Measurement Validation. *International Journal on Engineering Applications (IREA)*, 12(2), 126. <https://doi.org/10.15866/irea.v12i2.24440>
 35. Olekanma, O., Rodrigo, L.S., Adu, D.A., Gahir, B. (2024). Small- and medium-sized enterprises' carbon footprint reduction initiatives as a catalyst for green jobs: A systematic review and comprehensive business strategy agenda. *Business Strategy and the Environment*, 33(7), 6911-6939. <https://doi.org/10.1002/bse.3846>
 36. Pavlova, M. (2018). Fostering inclusive, sustainable economic growth and “green” skills development in learning cities through partnerships. *International Review of Education*, 64(3), 339-354. <https://doi.org/10.1007/s11159-018-9718-x>
 37. Pham, D. D.T., Paillé, P. (2019). Green recruitment and selection: an insight into green patterns. *International Journal of Manpower*, 41(3), 258-272. <https://doi.org/10.1108/IJM-05-2018-0155>

38. Pham, N.D.K., Dinh, G.H., Pham, H.T., Kozak, J., Nguyen, H.P. (2023). Role of Green Logistics in the Construction of Sustainable Supply Chains. *Polish Maritime Research*, 30(3), 191-211. <https://doi.org/10.2478/pomr-2023-0052>
39. Piva, E. (2024). Green logistics and new challenges of sustainability: a conceptual framework. *J-Reading*, 1, 23-37. <https://doi.org/10.4458/6915-02>
40. Podgórnaiak-Krzykacz, A., Przywojska, J. (2023). Public Policy and Citizens' Attitudes towards Intelligent and Sustainable Transportation Solutions in the City—The Example of Lodz, Poland. *Energies*, 16(1). <https://doi.org/10.3390/en16010143>
41. Podgórnaiak-Krzykacz, A., Przywojska, J., Trippner-Hrabi, J. (2022). A Public Value-Based, Multilevel Evaluation Framework to Examine Public Bike-Sharing Systems. Implications for Cities' Sustainable Transport Policies. *Transport and Telecommunication Journal*, 23(2), 180-194. <https://doi.org/10.2478/tjt-2022-0016>
42. Polinori, P., Marcucci, E., Gatta, V., Bigerna, S., Andrea Bollino, C., Micheli, S. (2018). Eco-labeling and sustainable urban freight transport : How much are people willing to pay for green logistics ? *International Journal of Transport Economics*, 45(4), 631-658. <https://doi.org/10.19272/201806704006>
43. Prasetyo, D.W., Kusmaningtyas, A., Mujanah, S. (2024). Green Competence Building, Green Employee Involvement and Green Work-Life Balance to Improve Environmental Performance through Green Organizational Culture. *Journal of Environmental Management and Tourism*, 15(1), 69. [https://doi.org/10.14505/jemt.v15.1\(73\).06](https://doi.org/10.14505/jemt.v15.1(73).06)
44. Rosano, M., Cagliano, A.C., Mangano, G. (2022). Investigating the environmental awareness of Logistics Service Providers. The case of Italy. *Cleaner Logistics and Supply Chain*, 5. <https://doi.org/10.1016/j.clscn.2022.100083>
45. Salas-Navarro, K., Castro-García, L., Assan-Barrios, K., Vergara-Bujato, K., Zamora-Musa, R. (2024). Reverse Logistics and Sustainability: A Bibliometric Analysis. *Sustainability*, 16(13), 5279. <https://doi.org/10.3390/su16135279>
46. Shah, K.J., Pan, S.-Y., Lee, I., Kim, H., You, Z., Zheng, J.-M., Chiang, P.-C. (2021). Green transportation for sustainability: Review of current barriers, strategies, and innovative technologies. *Journal of Cleaner Production*, 326, 129392. <https://doi.org/10.1016/j.jclepro.2021.129392>
47. Shoaib, M., Abbas, Z., Yousaf, M., Zámečník, R., Ahmed, J., Saqib, S. (2021). The role of GHRM practices towards organizational commitment: A mediation analysis of green human capital. *Cogent Business & Management*, 8(1). <https://doi.org/10.1080/23311975.2020.1870798>
48. Subramanian, N., Abdulrahman, M.D., Wu, L., Nath, P. (2016). Green competence framework: evidence from China. *The International Journal of Human Resource Management*, 27(2), 151-172. <https://doi.org/10.1080/09585192.2015.1047394>
49. Sudolska, A. (2022). Green Competences and Responsible Innovation – Exploring the Reciprocity of Concepts Relationship. *Problemy Zarządzania - Management Issues*, 2(96), 156-175. <https://doi.org/10.7172/1644-9584.96.8>

50. Sudolska, A., Łapińska, J. (2023). Corporate stakeholder orientation and green competencies concepts: unraveling the nexus. *Scientific Papers of Silesian University of Technology Organization and Management Series*, 180. <https://doi.org/10.29119/1641-3466.2023.180.33>
51. Sulich, A., Kozar, Ł.J. (2024). Green competences: A review and future research in the context of green human resource management. *Economics and Environment*, 89(2), 713. <https://doi.org/10.34659/eis.2024.89.2.713>
52. Tetteh, F.K., Owusu Kwateng, K., Mensah, J. (2024). Green logistics practices: A bibliometric and systematic methodological review and future research opportunities. *Journal of Cleaner Production*, Vol. 476. Elsevier Ltd. <https://doi.org/10.1016/j.jclepro.2024.143735>
53. Torres, J., Jiménez-Meroño, E., Soriguera, F. (2024). Forecasting the Usage of Bike-Sharing Systems through Machine Learning Techniques to Foster Sustainable Urban Mobility. *Sustainability*, 16(16), 6910. <https://doi.org/10.3390/su16166910>
54. Vengadesh, S., Chinna, P.R., Aravindaraj, K. (2023). A Bibliometric Analysis of Research Trends in Goods Transportation Using the Scopus Database. *Business Perspectives and Research*, 227853372211488. <https://doi.org/10.1177/22785337221148807>
55. Vienažindienė, M., Tamulienė, V., Zaleckienė, J. (2021). Green Logistics Practices Seeking Development of Sustainability: Evidence from Lithuanian Transportation and Logistics Companies. *Energies*, 14(22), 7500. <https://doi.org/10.3390/en14227500>
56. Vincek, Z.L., Gregurec, I., Kovšca, V. (2023). Exploring the trend of the research on Logistics 4.0. *Logforum*, 19(3), 359-409. <https://doi.org/10.17270/J.LOG.2023.859>
57. Wang, X., Javaid, M.U., Bano, S., Younas, H., Jan, A., Salameh, A. (2022). Interplay among institutional actors for sustainable economic development—Role of green policies, ecopreneurship, and green technological innovation. *Frontiers in Environmental Science*, 10. <https://doi.org/10.3389/fenvs.2022.956824>
58. Wodnicka, M., Królikiewicz, B. (2024). Blockchain in logistics in the context of sustainable development. *Scientific Papers of Silesian University of Technology. Organization and Management Series*, 202, 605-620. <https://doi.org/10.29119/1641-3466.2024.202.37>
59. Yafi, E., Tehseen, S., Haider, S.A. (2021). Impact of Green Training on Environmental Performance through Mediating Role of Competencies and Motivation. *Sustainability*, 13(10), 5624. <https://doi.org/10.3390/su13105624>
60. Young, W., Hwang, K., McDonald, S., Oates, C.J. (2010). Sustainable consumption: green consumer behaviour when purchasing products. *Sustainable Development*, 18(1), 20-31. <https://doi.org/10.1002/sd.394>

STRATEGIC USE OF COSTLY INNOVATION

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Purpose: The aim of this paper is to examine reasons for lagging in innovation of past technological leaders and incentives of entrants to a market to invest more despite smaller market share.

Approach: Examples of banks vs. fintechs and combustion engine carmakers vs. electric carmakers are used as motivation to construct an oligopolistic competition model that demonstrates reasons for giving up development by existing market leaders.

Findings: In the presented model, an impact of costly innovation is non-monotone and hence some incumbents have limited incentives to innovate. Those findings justify why combustion engine carmakers compete with new electric vehicle carmakers in a way less aggressive manner than implied by their market share.

Research limitations: This paper is focused on theoretical framework without extended empirical analysis of existing data. Further research should focus on confronting those findings with data on the banking or automotive sectors.

Practical implications: This paper provides theoretical foundations for analyzing markets with costly innovation and entry by new competitors. It provides a set of cases where competition has to be analyzed separately.

Originality: Existing industrial organization models do not provide economic explanation for actions of industry incumbents faced with innovating entrants that match observed actions in some industries. Such actions are mostly explained by management inaction and not rational economic choices. The presented model provides a novel way to approach this issue which does not contradict rational strategic choices of market incumbents.

Keywords: strategic innovation, competition with innovation, oligopoly.

Category of the paper: Research paper.

1. Introduction

In several industries, established firms operating for several years face competition from new entities that use technology to their advantage. Surprisingly, incumbents often delay their investments in new technologies and later face decreasing market share. Nokia decided not to push investments into large screen touch operated phones (Cord, 2014). Kodak decided not to pursue digital photography (Hess, 2014). Those decisions are often classified as management

mistakes and used as examples of strategic errors of management of such companies. Using this ‘missed opportunity’ line of reasoning implies that large, established companies either did not have a proper understanding of their market or did not analyze strategic prospects of new technologies. The goal of this paper is to demonstrate that incumbents valuing the present stream of income and having a strong market position may decide not to invest, even faced with an aggressive entrant using technology to its advantage.

The structure of the paper is as follows. In the next section, two motivating examples are presented. The literature review on relevant oligopolistic competition models follows. Further discussion of key models of competition with investment or innovation precedes the description of the model, its assumptions and discussion of results. Summary of results and their consequences for future competition and investment strategies closes the paper.

2. Motivating examples

There are several examples of once market dominating firms which ignored some technological change which turned out to be a reason of their later demise. The question posed by this paper is whether such decisions were mistakes or in short term they were rational. Two examples motivating this research are the reaction of European banks to the introduction of PSD II regulation and the slow adoption of electric powertrains by dominating producers of combustion engine-powered cars. The case of PSD II regulation is a leading motivating example used in this research.

2.1. PSD2 directive and competition between banks and fintechs

The financial market in the countries of the European Union is regulated based on national regulations as well as harmonization of EU directives. The regulatory framework should be consistent across the whole EU. The recent financial crisis and the development of new technologies demonstrated how deeply regulations might impact markets in a way not predicted before their implementation. Therefore, all new regulations should be considered in as broad context as it is possible. We should carefully analyze how new regulations will impact strategic choices of existing entities and what strategies new entrants may use. It may be easier to analyze the impact of new regulations from the standpoint of the current market situation, considering only how incumbent companies will act, but this may lead to confusing or wrong implications of new regulations.

Two key European financial regulations, which can substantially change how financial markets operate, are directives PSD2 and MiFID2. The PSD2 directive (BearingPoint, 2016; European Parliament, 2015) regulates how to carry out payments and regulates operations of

entities which may, on behalf of the clients of banks, mediate payments. The MIFID2 directive concerns the functioning of the investment market.

There is a consensus among practitioners about the considerable impact of these regulations. However, the economics literature discussion of the impact of PSD2 and MIFID2 on the markets and financial institutions is very limited. The aim of this work is to demonstrate how existing competition models may help us understand the behavior of banks after PSD2 implementation. In the model, incumbent banks have the possibility to invest in technology before competing against potential entrant – fintech company. In the equilibrium, incumbents with lower cost tend to invest more than those with higher costs. Hence, following PSD2 implementation, it is likely that banks that already have cost advantage will strengthen their position in coming years. Banks with lower costs will remain competitive against fintechs, while legacy banks will remain less competitive.

Adopted in October 2015, Payment Services Directive 2 (PSD2) is the development and modification of the PSD directive adopted in 2007. While the PSD directive focused on the harmonization of payment rules in existing electronic systems, PSD2 goes much further.

The aim of PSD2 is to enhance consumer protection, support innovation in the financial sector, and improve the security of payment services in the European Union. Within a period of two years from the adoption of the new regulation, Member States should implement the provisions of the directive to local regulations. The key issues that the revised legislation addresses are changes to the definition of a transaction and how to define it; stricter requirements for proof of identity by payment service providers (PSP); faster handling of payment service complaints; payment initiation services and account information services. From the perspective of consumer protection, key issues are requirements related to validating the customer's identity, reducing the time to process complaints up to 15 days, limiting the liability of payment service users and requiring a free card exchange in the event of a loss.

But from the perspective of the banking market, other issues are far more important. The most important is the introduction of possibility to initiate payment by a third party and the obligation for banks to make available information about bank accounts to third parties who got the consent of banks' customers. In the first case, the directive indicates the need to enable the customer to initiate online payments through a third party and define such entities as payment information service providers (PISP). This possibility means that an alternative to payment cards will be provided for online transactions because with the consent of the consumer PISP will be able to initiate payment directly from the bank account. In the second case, the directive introduces the concept of the account information service provider (AISP). With the consent of clients, AISP should have access to information about the consumers' bank accounts. This information should include not only the basic info but also the history of the account and its status.

In practice, introducing the possibility to initiate payments and provision of access to account information combined with the tightening of security requirements puts an enormous burden of adapting to new regulations on banks and existing payment institutions. Banks must provide the possibility to obtain account information directly from computer banking systems and to initiate certain operations in these systems. This means opening to the external users of systems that now communicate only with banks' own applications provided to their customers. This creates plenty of opportunities for potential illegal activity. Preventing such acts will be the responsibility of banks.

New regulations can open new opportunities to entities broadly identified as fintech companies. In most cases, fintechs are entities that use new technologies to offer products that are either complementary or competitive to related products offered by regulated financial institutions. Typically, such products do not require fintechs to act as regulated entities. The PSD2 directive will enable those companies to offer services related to banking products. An example of such a service can be software that allows access to bank accounts in multiple banks in different countries of the European Union within a single interface. In this case, the provider of the software offers a service to access several accounts and several other services competitive with banks' products. For banks, this scenario implies the risk of loss of continuous and direct contact with their clients.

From a consumer perspective, new regulations can mean easier access to services provided by existing institutions, as well as the possibility of using new innovative services offered in parallel.

2.2. Competition of combustion engine carmakers and electric vehicles producers

Traditional carmakers knew about the possibility of producing electric vehicles for a long time. Early attempts to produce electric cars can be dated as early as 19th century (Patel et al., 2020). Despite this, Tesla gained substantial handicap due to the inaction of other carmakers. Similarly to the previous example, one can argue that the cost of investment in technology change was so high for traditional carmakers that they allowed Tesla and other companies to gain ground on the market.

In such setting, car is a homogeneous good and potential buyers consider purchase based on a total cost of ownership which may be considered lower for electric cars. Therefore, entrants, such as Tesla, can gain substantial market share due to the lack of initiative of traditional carmakers, which are reluctant to invest in new electric powertrains and design of electric vehicles.

3. Literature review

Literature related to this topic can be divided into three main areas: studies focusing on practical issues related to regulatory changes arising, studies on competition between banks, and the texts on the modeling of imperfect competition and strategic innovation.

The literature on regulatory issues is mainly the European Union's documentation (European Parliament, 2015) and comments on the existing regulations indicating several possible scenarios for financial institutions to achieve compliance (BearingPoint, 2016; McKinsey&Co et al., 2018; Cortet et al., 2016). The focus is on how the situation of existing institutions will change with the implementation of new regulation. Some analysts also try to foresee how strategies of financial institutions will change due to changes in regulatory regime (Evry, 2016). Such analysis is based on potential scenarios of market development, and hence can provide us with insight into how existing financial institutions may think about the strategic impact of new regulations.

From the perspective of this paper, much more relevant is the literature on modelling imperfect competition in a broader sense. The key ingredient in presented considerations is how investments impact competition between incumbents and entrants. Interesting perspective provided classic articles on oligopoly and entry barriers – (Milgrom, Roberts, 1982; Dixit, 1980; Salop, 1979; Kreps, Scheinkman, 1983; Schmalensee, 1981). A broader discussion of (Dixit, 1980) and (Kreps, Scheinkman, 1983) is provided later in this paper.

In the case of modelling competition between banks, the existing literature focuses on the challenges posed by the recent financial crisis and liquidity and risk-related issues – (Goddard, Wilson, 2009; Fernandez et al., 2016; Schaeck, Cihak, 2012). Those papers discuss how to model competition between banks looking closely into limitations of banking activity. The key relationship in this part of the literature connects capital and willingness to take the risk. In this setting, competition between financial institutions looks more like competition for resources or providing investors with a preferred risk profile. This approach may not be helpful when we need into account fintechs as bank competitors because risk profile, sources of funding and regulations may be substantially different for those companies.

4. Competition modelling

What distinguishes banks from other financial institutions, such as insurance companies or investment fund companies, is the frequency of contacts with a customer. More importantly, this is usually a client-initiated contact. This allows banks to know their customers better than other financial institutions and offer them new products if they meet the capital requirements and the cost of providing the product is sufficiently low.

The purpose of PSD2 was to create new opportunities for innovative companies. However, AISP services may be interpreted as a possibility to distribute financial products to banks' clients without the necessity to build the costly banking infrastructure. Hence, banks will have to face the possibility of entry of new players that have considerably lower costs.

One can look at the cost of running banking operations from the point of view of two sources of costs. First, banks must acquire enough capital and simultaneously invest in technology to provide banking products efficiently. Second, banks will compete for customers. It is safe to assume that in such settings most of the banking products will be homogenous and therefore banks will compete in prices. This approach may have important consequence for equilibrium in such model. Simple competition in prices (i.e., Bertrand model) in equilibrium leads to cutting prices down to marginal costs level and erasing all economic profits of competing entities (Tirole, 1988). Because banks first acquire capital and invest in technology, we can use insight from other research to simplify this setting without loss of generality.

It is worth noting that looking at competition from the standpoint of setting prices of homogeneous product disregards all considerations about the product differentiation and impact of capital requirements in some industries.

4.1. Kreps-Scheinkman model

Assuming competition in prices while selling homogenous goods leads to an equilibrium where firms cut down prices to the marginal cost level. This prediction is problematic for a variety of homogenous goods. When price competition is preceded by setting up production capacity, the equilibrium no longer falls into the price cutting trap. Kreps & Scheinkman (1983) showed that costly construction of production capacity followed by price competition yields Cournot outcome in the whole game. Hence, despite the price competition and homogeneity of companies' product, they can achieve positive economic profits – higher than profits in the case of perfect competition. Similar results are also presented by (Moreno, Ubeda, 2006).

We can interpret this result in several ways. First, the margin realized by banks in the distribution process is equal to the margin realized in an oligopoly with price competition. In the price competition model, competitors lower the price to an equivalent level of perfect competition. This means that it is not possible to increase the competitiveness of the market for the distribution of banking products. Second, equilibrium in Kreps-Scheinkman model is subgame perfect. Therefore, decisions on the acquisition of capital by banks (i.e., construction of production capacity) will remain unchanged in equilibrium even if the distribution decisions are taken independently of decisions concerning the acquisition of capital. In this case, entry of an additional entity will change the outcome through supplying additional capacity to the market.

Kreps and Scheinkman result allows for simplification of earlier considerations about the competition in the banking services market. A model, where banks acquire capital and invest in technology to compete in prices, can be replaced by a model where banks invest in

technology to lower their marginal costs in the competition phase and later compete in quantities (i.e., Cournot model). This setting allows for the easier introduction of the entrant in the model.

4.2. Competition preceded by innovation – Dixit model

The complementary approach was adopted by Dixit in his paper on strategic innovation (Dixit, 1980). The competition is a three-step process – the incumbent chooses how much to invest in minimal production capacity, then the potential entrant decides whether to enter the market and, in the case of entry, companies compete in quantities. In the equilibrium, the company which decides to invest in a production capacity can discourage its competitor from entering a new market by building large production capacities and thus reducing potential profits of the entrant.

In the context of our discussion, the equilibrium in Dixit model can be interpreted as a scenario where banks invest before implementation of PSD2 to discourage potential entrants. This is a reasonable interpretation of Dixit results because investors in all fintech companies pay close attention to the number of consumers acquired by these companies. Further financing depends on the pace of development of these companies.

An interesting aspect of both presented models of competition with prior investment is information carried by earlier investments. In both cases, a firm investing in periods preceding the competition on the market, deliberately influences payoffs in subsequent periods. Investment is a costly signal of a commitment to defend the market position of the incumbent.

Unaddressed remains merging investment in technology followed by the potential entry. The simplest model to address this topic would require costly investment in technology followed by competition. Gaining technological advantage must be sufficiently costly to avoid cases where the marginal cost of improving technology is always lower than the marginal benefit.

5. Model

Two incumbent firms denoted by A and B compete in quantities with one entrant denoted by F . Initial marginal costs are denoted by $c_l \in [0, M]$ for $l \in \{A, B, F\}$. Inverse demand function for their products is $P(Q) = M - Q$.

The game between incumbents and entrant is split into three phases. First, incumbents simultaneously decide how much to invest in technology. Afterward, an entrant company enters the market, and finally all three entities compete in quantities supplied to the market. See figure (Figure 1). Technology investment by each incumbent is observed by the entrant and other

incumbents. In such a game, a new company always enters the market. A brief discussion of costly entry is presented later in this section.

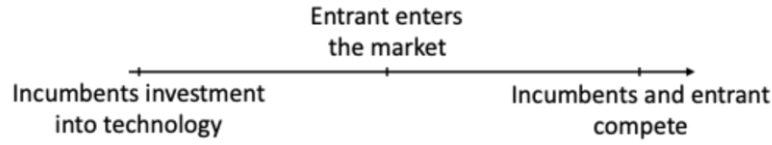


Figure 1. Sequence of actions in the model.

Incumbents capacities are given exogenously. As in (Kreps, Scheinkman, 1983) competition in quantities can be interpreted as the outcome of a capacity building stage followed by a price competition stage and therefore the additional complexity of capacity construction is removed from the model.

Through initial investments in technology, incumbents can lower their marginal costs. Investments' cost is a convex-increasing function such that $t(0) = 0$ and $t'(i) > 0$, $t''(i) > 0$ for $i > 0$. That is, small advances in technology are cheaper than big leaps. Suppose

$$t(i) = Ti^2 \quad (1)$$

for $T > 1$ and $i > 0$ where i denotes investment into incumbents' technology. Therefore, if an incumbent $l \in \{A, B\}$ invests $c(i_l)$ into improvement of its technology, the marginal constant cost is equal to $c_l - i_l$.

Competition between incumbents and entrant can be modelled as a dynamic game between them, where incumbents first choose investment levels and then quantities. The entrant chooses only quantities. Joint supply and inverse demand function determine market price while payoffs of incumbents are equal to profits

$$\Pi_l = (M - q_A - q_B - q_F)q_l - (c_l - i_l)q_l - t(i_l) \text{ for } l \in \{A, B\} \quad (2)$$

and payoff of entrant is equal to

$$\Pi_F = (M - q_A - q_B - q_F)q_F - c_F q_F, \quad (3)$$

where q_l denotes quantity supplied to the market.

5.1. Assumptions

Description of the model contains several assumptions. The assumption about the form of competition on the market that is competing in quantities instead of more intuitive competition in prices, relates to Kreps and Scheinkman model, where prior investment in production capacity makes those two forms of competition give the same Cournot outcome. That is why in the model there is no reference to the formation of incumbents' capacity.

The more important assumption is how incumbents invest in their technologies. Strictly increasing the convex cost of investment is consistent with how difficult significant changes in the legacy infrastructure of incumbents are. Small changes and adjustments are usually easy, despite being costly. Large adjustment leading to relevant cost reduction is costly

and risky because they usually involve replacing a substantial part of infrastructure. For the sake of an argument, a specific form of the cost function is used in the model. T parameter allows for changing how steeply cost of new technology grows. It is possible to get most of the presented later results with more general cost functions, but presentation is less convenient analytically. Furthermore, notice that there is a need to control for boundary conditions while looking for optimal investment level. Optimal investments may lead to costs going below zero.

Entry in the basic model is costless. This assumption simplifies the analysis but also is consistent with the behavior of new technology companies. Pressure from investors and willingness to test new solutions on the financial markets often make new companies enter already crowded markets to test their technology.

5.2. Solution concept

The most applicable solution concept for dynamic games as the one presented earlier is subgame perfect Nash equilibrium. Backward induction, in this case, implies that we have to solve for the equilibrium in the quantity competition stage with investment levels given. The results for the final stage of the game can be used to determine optimal investment levels.

Using backward induction to find subgame perfect Nash equilibrium may give only one of the potential solutions. With quantity competition in the last stage, that cannot be the case. To account for similar scenarios, it is necessary to analyze the possibility of costly entry into the market. That is how entry deterrence is modelled in Dixit model.

6. Results and discussion

6.1. Equilibrium without entrant

Given profit functions of incumbents

$$\Pi_l = (M - q_A - q_B)q_l - (c_l - i_l)q_l - t(i_l) \text{ for } l \in \{A, B\} \quad (4)$$

the first order conditions in the last stage game equilibrium are

$$\frac{\partial \Pi_l}{\partial q_l} = 0 \text{ for all } l. \quad (5)$$

Second order conditions for a local maximum are trivially satisfied and therefore, using the convention of denoting by $-l$ the other incumbent and solving for q_l , we have

$$q_l = \frac{(c_{-l} - i_{-l}) - 2(c_l - i_l) + M}{3}. \quad (6)$$

It implies that equilibrium profits of each incumbent are equal to

$$\Pi_l = \frac{(2(c_l - i_l) - (c_{-l} - i_{-l}) - M)^2}{9}. \quad (7)$$

First order conditions in the first stage are

$$\frac{\partial \Pi_l}{\partial i_l} = 0 \text{ for all } l. \quad (8)$$

Second order condition for local maximum is satisfied. Therefore, substituting $t(i) = Ti^2$, in interior solution where $0 \leq i_l \leq c_l$ we get equilibrium investment levels of investments

$$i_l = \frac{2(3Tc_{-l} - 6Tc_l + 2c_l + 3MT - 2M)}{(3T - 2)(9T - 2)} \quad (9)$$

and equilibrium profits equal to

$$\Pi_l = \frac{9T^2(3Tc_{-l} - 6Tc_l + 2c_l + 3MT - 2M)^2}{(3T - 2)^2(9T - 2)^2} \text{ for } 0 \leq i_l \leq c_l. \quad (10)$$

Observe that condition $0 \leq i_l \leq c_l$ needs to be satisfied. Because $c_l \in [0, M]$ boundary solutions are either 0 or c_l . Solving for boundary conditions, we get

$$I_l^L = \frac{2(3Tc_{-l} + 3MT - 2M)}{3T(9T - 4)} \text{ and } I_l^H = \frac{3Tc_{-l} + 3MT - 2M}{2(3T - 1)}. \quad (11)$$

For $0 \leq c_l \leq I_l^L$ the company will invest as much as c_l in equilibrium. For $I_l^H \leq c_l \leq M$ company will invest nothing in equilibrium. Therefore, we can split possible values of c_l into three intervals, presented in figure (Figure 2). Notice that

$$\frac{\partial I_l^L}{\partial c_{-l}} > 0 \text{ and } \frac{\partial I_l^H}{\partial c_{-l}} > 0. \quad (12)$$

and hence the interval of where interior solutions are possible moves closer to M as c_{-l} increases.



Figure 2. Split of possible values of c_l into intervals.

We can also notice that

$$\frac{\partial I_l^L}{\partial T} < 0 \text{ and } \frac{\partial I_l^H}{\partial T} > 0. \quad (13)$$

where the first inequality holds for sufficiently large c_{-l} .

With this split of potential investment levels, one can notice that in equilibrium, investment levels are non-monotone. Given an analytical representation of equilibrium investment levels:

$$i_l = \begin{cases} c_l & \text{for } 0 \leq c_l \leq I_l^L, \\ \frac{2(3Tc_{-l} - 6Tc_l + 2c_l + 3MT - 2M)}{(3T - 2)(9T - 2)} & \text{in interior solution, i.e. } c_l \in [I_l^L, I_l^H], \\ 0 & \text{for } I_l^H \leq c_l \leq M. \end{cases} \quad (14)$$

Lower and upper bounds of the region, where investments have an interior solution, depending on the cost's levels of the other company. Moreover, for the assumed shape of the technology investment function, the boundaries of an interior solutions region are linear functions of c_{-l} . Graphical representation of the region where exist interior solutions for optimal investment level of one firm is depicted by gray area in figure (Figure 3a). In the region on the left side, firm investment results in zero marginal cost in the competition phase. In the region on the right side, a firm does not invest at all.

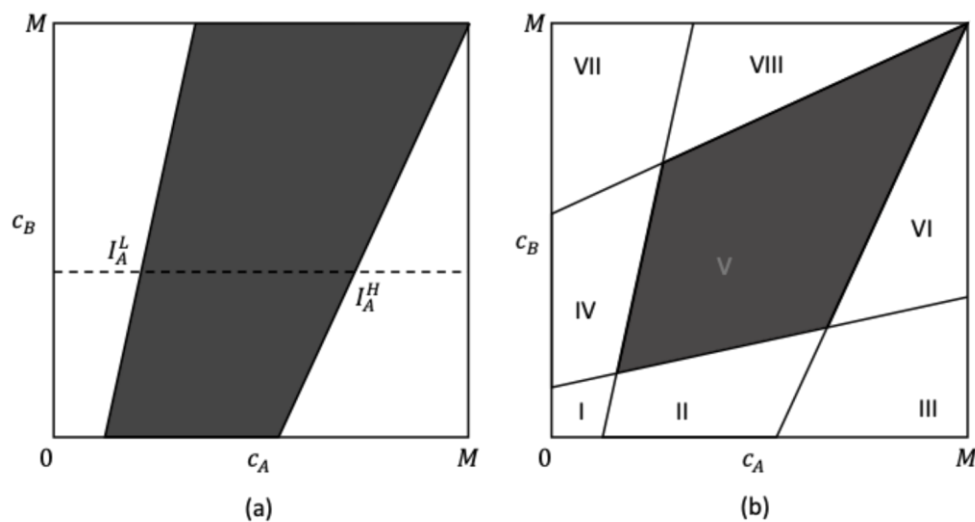


Figure 3. Types of equilibria with no entrant.

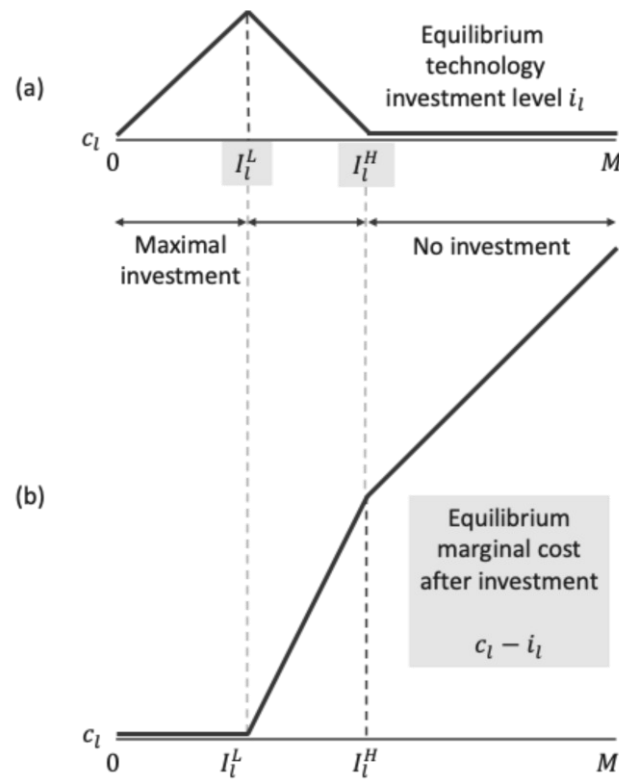


Figure 4. Equilibrium technology investments and resulting costs with no entrant.

Putting together this result for both firms, we get eight regions presented in figure (Figure 3b). Only in the region marked V both firms' investment levels are in $(0, c_l)$. In other regions, investment levels can be classified in the way described in the table (**Błąd!** **Nie można odnaleźć źródła odwołania.**

Table 1.

Equilibrium strategies of incumbents ordered by sets depicted in figure (Figure 3)

VII Incumbent A invests to reduce marginal cost to 0, while incumbent B does not invest.	VIII Investment of incumbent A does not reduce its cost to 0 and Incumbent B does not invest.	
IV Only A will invest to reduce marginal cost to 0. Investment of incumbent B does not reduce its cost to 0.	V Both incumbents invest and their resulting marginal cost is larger than 0.	VI Investment of incumbent B does not reduce its cost to 0 and incumbent A does not invest.
I Both companies invest to reduce marginal cost to 0.	II Only B will invest to reduce marginal cost to 0. Investment of incumbent A does not reduce its cost to 0.	III Incumbent B invests to reduce marginal cost to 0, while incumbent A does not invest.

Source: Own elaboration.

All considerations above rely on the shape of optimal technology investment in equilibrium and resulting cost levels, which are presented in figure (Figure 3).

Notice that in the equilibrium, incumbents with lower marginal costs invest more than incumbents with higher initial costs. The source of this surprising result lies in the difference between the marginal cost and benefit of technology investment. On one hand, investing in technology increases profitability, but the cost of investment is regulated by parameter T or more generally steepness of function $t(\cdot)$. By choosing the quadratic technology function, we matched it with the profit function. This simplifies analysis of the model but generally the same results can be obtained with sufficiently quickly increasing convex functions.

As T increases cost of implementing a new technology changes. In particular, it becomes more costly to achieve technology advance as T grows. Notice also that we can rewrite the equations for I_t^L and I_t^H in the following way:

$$I_t^L = \frac{2(3Tc_{-l} + 3MT - 2M)}{3T(9T - 4)} = \underbrace{\frac{6T}{3T(9T - 4)}}_{\substack{\partial \cdot / \partial T < 0 \\ T > 1}} c_{-l} + \underbrace{\frac{6MT - 4M}{3T(9T - 4)}}_{\substack{\partial \cdot / \partial T < 0 \\ T > 1.052}} \quad (15)$$

and

$$I_t^H = \frac{3Tc_{-l} + 3MT - 2M}{2(3T - 1)} = \underbrace{\frac{3T}{2(3T - 1)}}_{\partial \cdot / \partial T < 0} c_{-l} + \underbrace{\frac{3MT - 2M}{2(3T - 1)}}_{\partial \cdot / \partial T > 0}. \quad (16)$$

That implies that as T goes up the boundaries of the gray region in figure (Figure 3a) become steeper and move further away from each other.

6.2. Equilibrium with entrant

Given profit functions of incumbents $l \in \{A, B\}$ and entrant F

$$\Pi_l = (M - q_A - q_B - q_F)q_l - (c_l - i_l)q_l - t(i_l) \text{ for } l \in \{A, B\} \quad (17)$$

$$\Pi_F = (M - q_A - q_B - q_F)q_l - c_F q_F \quad (18)$$

the first order conditions in the last stage game equilibrium are

$$\frac{\partial \Pi_j}{\partial q_j} = 0 \text{ for all } j \in \{A, B, F\}. \quad (19)$$

Following the same reasoning as in the previous section, those first order conditions result in:

$$q_l = \frac{c_F + (c_{-l} - i_{-l}) - 3(c_l - i_l) + M}{4} \text{ for } l \in \{A, B\}, \quad (20)$$

$$q_F = \frac{(c_A - i_A) + (c_B - i_B) - 3c_F + M}{4}. \quad (21)$$

The resulting equilibrium interior investment levels are

$$i_l = \begin{cases} c_l & \text{for } c_l < I_l^L \\ \frac{3}{2} \left(\frac{c_F - 2c_l + M}{8T - 3} + \frac{4T(c_{-l} - c_l)}{(4T - 3)(8T - 3)} \right) & \text{for } c_l \in [I_l^L, I_l^H] \\ 0 & \text{for } c_l < I_l^H \end{cases} \quad (22)$$

for

$$I_l^L = \frac{3}{4T} \frac{(c_F + M)(4T - 3) + 4Tc_{-l}}{16T - 9} \text{ and } I_l^H = \frac{(c_F + M)(4T - 3) + 4Tc_{-l}}{6(2T - 1)}. \quad (23)$$

Notice that the existence of an entrant changes an equilibrium structure. It is possible that in the equilibrium no incumbent invests in new technology. Hence, there exists a new scenario where no entrant decides to invest in a new technology. Entrant that certainly enters the market leaves less space on the market for incumbent companies. Therefore, sometimes additional spending on a new technology would not improve the strategic position of incumbents. A new split of equilibrium actions of incumbents is presented in figure (Figure 5).

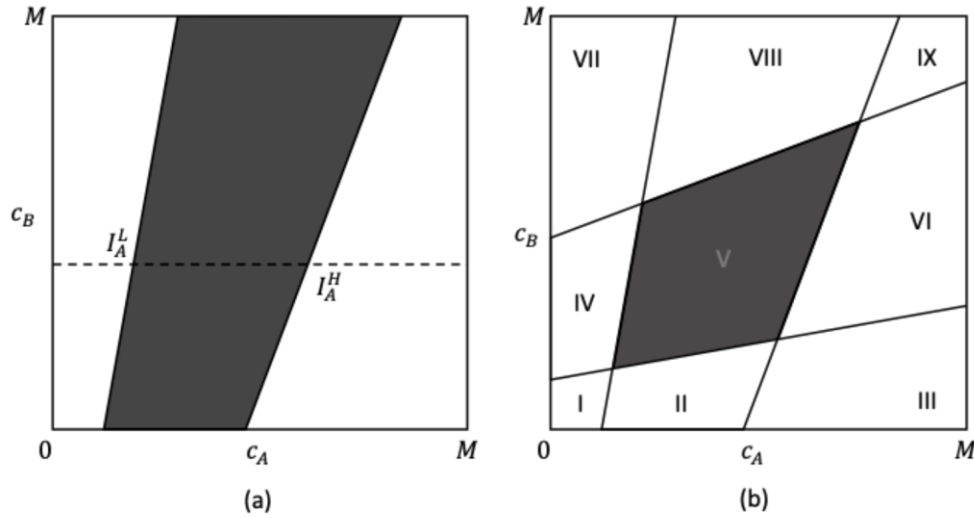


Figure 5. Types of equilibria with entrant.

Depending on each incumbent, there exists a set of interior solutions where companies lower their initial costs to some non-zero level. The shape of i_l remains identical to the one presented in figure (Figure 4).

6.3. Comparative statics

Basic comparative statics of equilibrium investment levels for $c_l \in [I_l^L, I_l^H]$ are straightforward

$$\frac{\partial i_l}{\partial c_l} < 0, \frac{\partial i_l}{\partial c_{-l}} > 0, \text{ and } \frac{\partial i_l}{\partial c_F} > 0. \quad (24)$$

The other key comparative statics in the presented model is how investment levels of incumbents change in equilibrium depending on the cost structure of the entrant. It is straightforward to show that

$$\frac{\partial I_l^L}{\partial c_F} = \frac{3}{4T} \frac{4T-3}{16T-9} > 0 \text{ and } \frac{\partial I_l^H}{\partial c_F} = \frac{4T-3}{6(2T-1)} > 0. \quad (25)$$

Moreover, we have also $\partial I_l^H / \partial c_F > \partial I_l^L / \partial c_F$. That implies that when an entrant has higher initial costs compared to incumbents, the size of the region where companies invest in cost reduction is bigger. Entrant with relatively low initial costs will not be met with strong initial investments by incumbents.

This observation is interesting because it explains why entrants in areas where entry does not require substantial initial costs meet no competition from existing incumbents. The costs of investments in existing infrastructure do not justify spending. Incumbents prefer to hold on to the market share they have without overspending. This is obviously a consequence of the assumed investment cost function. We can expect that a market will behave similarly in equilibrium if we have convex and sufficiently quickly increasing costs. The convexity assumption in this case is in line with what we observe in spending of corporations on their IT infrastructure (Christensen, 1997).

6.4. Identical incumbents

So far, the analysis focused on the case of incumbents that have different marginal costs and, therefore, in an equilibrium they choose different investment levels. For the sake of simplicity, prior to analyzing costly entry, it is worthwhile to turn to the case of identical incumbents. The existence of identical incumbents in the analyzed model implies $c_A = c_B$ and the existence of symmetric equilibrium where both incumbents make the same investments into technological improvement of their marginal cost.

Notice that in the model without entrant, symmetric incumbents always invest in technology improvement. Area V in Figure 3.b denotes equilibria investment levels that reduce initial marginal cost. Area I in Figure 3.b denotes equilibria where investments of both competitors reduce initial costs down to zero. It is straightforward to derive the levels of I^L and I^H in case of no entrant: $[2M/9T, M]$. The steps are as follows: (1) find equilibrium quantities, given initial cost and investment; (2) find equilibrium investments using first order conditions on total profits of both incumbents; (3) verify for what range of investments you have them in $[0, c]$ where c denotes initial marginal costs. It is worth noting that in the symmetric case you have identical initial marginal cost and hence to find I^L and I^H it is not enough to plug c to formulas for asymmetric case – you must solve equations for I^L and I^H under condition that $c_A = c_B$. When incumbent's marginal costs fall into this region both firms invest into lowering their marginal cost in the investment phase but do not manage to lower it down to zero in equilibrium.

One can repeat the same line of reasoning in the case of an entrant with marginal cost c_F . In such case the interval where incumbents less than their initial marginal cost but more than zero is $[3(c_F + M)/16T, (c_F + M)/2]$. See figure (Figure 6).

Surprisingly, it implies that incumbents always invest more only when entrant has sufficiently small costs. To prove it is enough to consider two cases $c_F \in [0, 5/27M]$ and $c_F \in (5/27M, M]$. Notice that in the first case I^L on the lower left graph in figure (Figure 6) will be larger than I^L on the lower right graph in Figure 6 and therefore, all values of i_l will be larger in the case of no entrant.

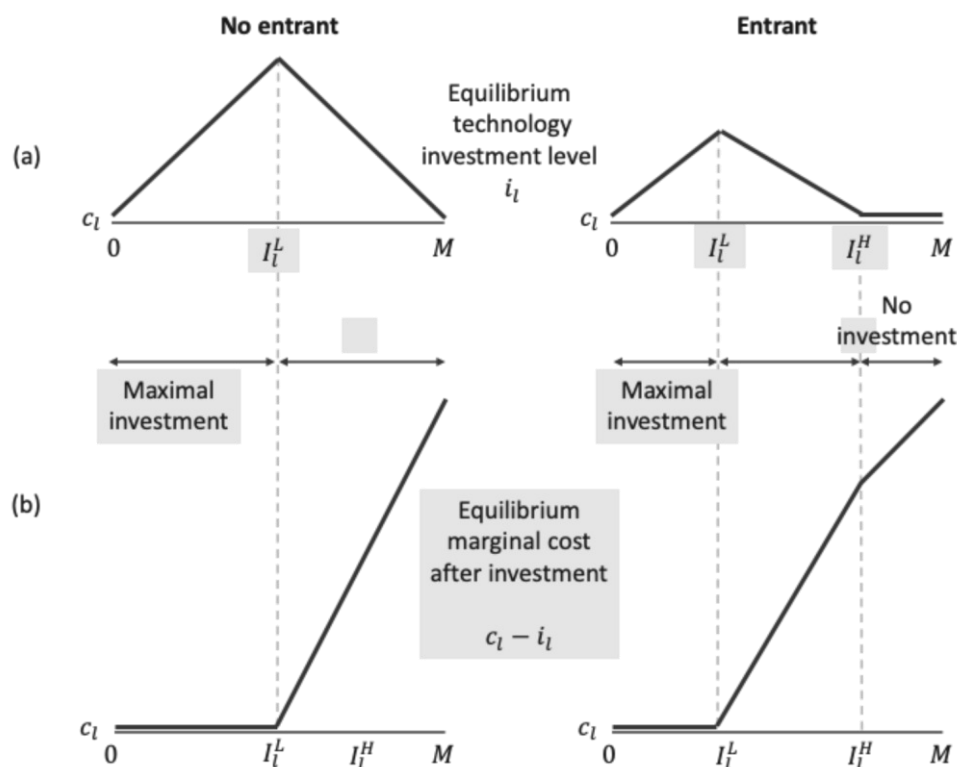


Figure 6. Equilibrium investment levels and resulting costs in the case of identical incumbents.

6.5. Costly entry with identical incumbents

In his paper, Dixit demonstrated that prior investments may deter entrants. The key for such a result is the possibility to commit. If the incumbent on the market cannot commit to fighting the entrant, then in most cases it will accommodate entry as more profitable than engaging in strong competition that will hurt all companies present on the market. On the other hand, when incumbent can commit to being tough in case of entry, it is possible to deter entry whatsoever.

So far, entrant in the model only made choice during the competition phase. Suppose the sequence of moves allows for an entrant to decide whether to enter the market. The sequence of actions in this case is presented in figure (Figure 7). Obviously, in the absence of other costs, in the framework presented in the previous section, the entrant would always enter. Thus, there is an additional cost that needs to be added. Hence, a rational entrant will decide to enter the market if and only if its profit will be higher than zero.

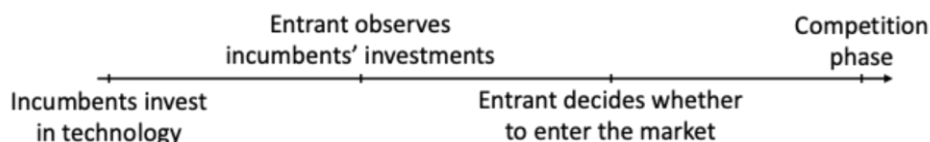


Figure 7. Sequence of decisions in case when an entrant can decide whether to enter the market.

Intuitively, the larger cost of entry, the smaller will be region IX in figure (Figure 5). Without developing an analytical solution to the equilibrium problem, we can conclude that results will have the same structure as before. The additional cost of entry will deter the entrant in some cases. An entrant with a sufficiently high cost will not enter the market.

7. Conclusions

The model presented in this paper provides insight why it is possible that rational incumbents do not innovate enough to keep up with an innovative entrant to the market. Despite the simplicity of the model, its subgame perfect equilibrium turns out to be quite complex. The main result is that smaller or less advanced incumbents may benefit more from innovating. Therefore, they are able to keep up with innovative entrants. The main limitation of the presented approach is the complexity of equilibrium. Considering a larger number of incumbents and a more general approach to cost of innovation may lead to the necessity of numerical modelling instead of clean analytical solutions.

There are three clear extensions of the presented model that are worth investigating. The first extension is using other technology cost functions to study the impact of assumptions of the presented model. Some results we can expect from making the technology cost function steeper are the same comparative statics we got with changes in T . More complex technology cost functions may considerably impact analytical part of the model and make solutions to some problems impossible to represent in a meaningful closed form.

Another extension is allowing for several periods of innovation. In such a model it is possible to observe how technology spending evolves. In multi-period setting, it should also be possible to verify how companies minimize total cost of innovation and how the trade-off between current profits and future innovation benefits work.

The third set of extensions is to add randomness to effects of innovation to see how randomness impacts earlier results.

The PSD2 directive substantially changes the way money on bank accounts may be used in the future. At the same time, most of the consumers are unaware of the changes that are coming to the financial sector. Some banks invest in technologies to safeguard themselves from regulatory regime changes.

Consulting companies published several reports on the possible outcome of PSD2 implementation (McKinsey&Co et al., 2018). The most far-reaching scenario, which will be the very rapid expansion of fintech, will prevent banks from distributing large-scale banking products themselves. A prerequisite for this market development scenario is that banks will make entry easy. This implies making interfaces that connect banking systems with fintech IT solutions widely and easily available. This implies substantial investments of banks that will

not improve their competitive position. Following the presented model, we can see that inside every bank, investment money will be split between funds for fulfilling regulatory obligations and investing into own bank's technology to effectively compete with fintech entrants.

An alternative scenario presented by the consulting firms is the situation where banks will fulfil regulatory obligations but do nothing to encourage fintech to use their systems and possibly limit access to their systems. The PSD2 introduces the obligation to allow access to the systems but at the same time imposes security and confidentiality constraints on banks. This gives them the ability to restrict access by creating non-friendly interfaces or extremely advanced security requirements. In this case, banks will take a strategic decision on the availability of information systems, guided by the possible scale of action and the efficiency. In this case, additional spending on information technology may be limited if it will not hurt banks' market position.

Those two scenarios essentially imply that smaller banks will have to compete with fintechs head-to-head to stay profitable. This finding is consistent with the presented model. Some institutions will not participate in the technological race because it would be far too costly. Others must match fintechs in their agility and willingness to innovate.

We do not yet know what the outcome will be stemming from the PSD2. However, today we can already observe actions of banks. It is particularly interesting looking from the point of past investments in technology. Most of the banks in developed markets invested in technology before the end of the last century. After implementing big core banking systems, new features were built on top of existing infrastructure. On the other hand, several banks in less developed markets, like those of CEE, invested in new core banking systems several years later. That gives those institutions instant cost advantage and the possibility to easily add new technologies to their existing systems. This path is clearly visible in payment technologies used across Europe. It is far easier to use advanced payment methods in CEE countries. The outcome of PSD2 is yet to be seen, but we can see that not all banks will use the same strategic options competing with new entrants to the financial services market.

Directives PSD2 and MiFID2 will substantially change the foundations of the financial markets in the coming years. However, to understand the possible impact of the new regulations, you need to go beyond typical models of banking services market. Better tools to understand the possible implications of upcoming changes are the models of imperfect competition from industrial organization literature. It is crucial for this approach to observe the decisions of market participants from the perspective of their strategic behavior.

References

1. BearingPoint (2016). Payment Services Directive 2 (PSD2). *Payment Services Directive 2 (PSD2)*.
2. Christensen, C.M. (1997). *The innovator's dilemma: When new technologies cause great firms to fail*. Harvard Business School Press.
3. Cord, D.J. (2014). *The decline and fall of Nokia*. Schildts & Söderströms.
4. Dixit, A. (1980a). The role of investment in entry deterrence. *Economic Journal*, 90(March), pp. 95-106.
5. Dixit, A. (1980b). The role of investment in entry deterrence. *Economic Journal*, 90(March), pp. 95-106.
6. European Parliament (2015). Psd2 Eng. *Official Journal of the European Union*.
7. Fernandez, A.I., Gonzalez, F., Suarez, N. (2016). Banking stability, competition, and economic volatility. *Journal of Financial Stability*, 22, pp. 101-120.
8. Goddard, J., Wilson, J.O.S. (2009). Competition in banking: A disequilibrium approach. *Journal of Banking and Finance*, 33(12), pp. 2282-2292.
9. Hess, R. (2014). KODAK: Rise and Fall of a Legend. https://www.academia.edu/11900256/KODAK_Rise_and_Fall_of_a_Legend_Organizational_Transformation_in_the_Case_of_Eastman_Kodak_Corporation?auto=download
10. Kreps, D.M., Scheinkman, J.A. (1983). Quantity Precommitment and Bertrand Competition Yield Cournot Outcomes. *The Bell Journal of Economics*, 14(2), p. 326. Available at: <http://www.jstor.org/stable/3003636?origin=crossref>.
11. Milgrom, P., Roberts, J. (1982). Predation, reputation, and entry deterrence. *Journal of Economic Theory*, 27(2), pp. 280-312.
12. Moreno, D., Ubeda, L. (2006). Capacity precommitment and price competition yield the Cournot outcome. *Games and Economic Behavior*, 56(2), pp. 323-332.
13. Patel, N., Bhoi, A.K., Padmanaban, S., Holm-Nielsen, J.B. (2020). *Electric vehicles: Modern technologies and trends*. Springer.
14. Salop, S.C. (1979). Strategic Entry Deterrence. *The American Economic Review*, 69(2), pp. 335-338.
15. Schaeck, K., Cihak, M. (2012). Banking Competition and Capital Ratios. *European Financial Management*, 18(5), pp. 836-866.
16. Tirole, J. (1988). The Theory of Industrial Organization: Jean Tirole. *The theory of industrial organization*, p. 207.

REVOLUTIONIZING MANAGEMENT: COMPETENCY BUILDING WITH CUTTING-EDGE TECHNOLOGIES

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Purpose: This study develops an integrated theoretical framework synthesizing Dynamic Capabilities Theory, Knowledge-Based View, Socio-Technical Systems Theory, and Digital Leadership to explain how organizations leverage emerging technologies to develop management competencies and enhance organizational performance.

Design/methodology/approach: The research employs a two-phase conceptual methodology: (1) systematic literature analysis of leading management and information systems journals across four theoretical domains, and (2) iterative framework development integrating theoretical perspectives with emerging technology contexts.

Findings: The framework reveals that management competencies are shaped by the interaction between emerging technologies and modern digital management theories, leading to distinct organizational performance outcomes. These competencies lead to organizational benefits. The framework's effectiveness is moderated by contextual factors.

Originality/value: The research offers three significant contributions: (1) advances theoretical discourse by providing a novel synthesis of contemporary digital management theories, (2) demonstrates practical relevance through actionable insights for developing technology-enabled management competencies, and (3) establishes empirically validated linkages between digital capabilities and organizational outcomes. The framework provides a comprehensive understanding of how organizations can effectively develop and leverage digital capabilities in the modern business landscape.

Keywords: management competencies, emerging technologies, digital transformation, organizational performance.

Category of the paper: Conceptual paper.

1. Introduction

In the context of digital transformation, organizations face the complex challenge of developing and leveraging management competencies that align with emerging technologies while driving organizational performance. As digital technologies continue to reshape business landscapes, the need for an integrated theoretical framework that explains the relationships between technological innovation, management competencies, and organizational outcomes becomes increasingly critical. The successful organizational transformation in the digital age is especially crucial in the context of sustainable development, where digital competencies directly influence organizations' ability to achieve sustainability goals and maintain competitive advantage (Kuzior et al., 2023; Lyeonov et al., 2024; Strielkowski et al., 2022). This is particularly relevant in educational contexts, where the integration of artificial intelligence (AI) technologies presents both opportunities and challenges for maintaining academic integrity while pursuing sustainable development goals (Artyukhov et al., 2024). The competencies play a vital role in promoting sustainable consumption patterns and responsible management practices, extending their impact beyond organizational boundaries to broader societal concerns (Kuzior et al., 2023).

This study addresses this gap by developing an integrated theoretical framework that synthesizes four complementary theoretical perspectives: Dynamic Capabilities Theory in digital contexts (Teece, 2018; Warner, Wäger, 2019), Knowledge-Based View in digital environments (Sambamurthy et al., 2003; Kane et al., 2015), Socio-Technical Systems Theory (Lyytinen, Newman, 2008), and Digital Leadership (Cortellazzo et al., 2019). Recent empirical research has further demonstrated how these theoretical perspectives interact with social and economic determinants to shape organizational outcomes (Vasylieva et al., 2023). Building on recent work examining digital competencies in management systems (Kuzior et al., 2023), this integration provides a comprehensive lens through which to examine how organizations develop and leverage digital capabilities for enhanced performance in the modern business landscape.

The framework identifies four breakthrough technologies that are fundamentally reshaping management capabilities: AI and machine learning, Internet of Things and edge computing, blockchain and distributed ledger technologies, and extended reality (XR) and quantum computing. These technologies contribute to the development of five essential management competencies: digital leadership, data-driven decision making, agile strategy formulation, cross-functional orchestration, and ethical tech governance. The framework further explicates how these competencies lead to specific organizational outcomes, including innovation output, operational efficiency, market responsiveness, sustainability metrics, and financial performance.

Our research makes three significant contributions to the field. First, it advances theoretical discourse by providing a novel synthesis of contemporary digital management theories, integrating previously disparate conceptual frameworks into a cohesive paradigm. Second, the study demonstrates substantial practical relevance through its delineation of actionable insights for developing technology-enabled management competencies, thereby bridging the often-encountered gap between theoretical constructs and pragmatic implementation. Third, the research establishes empirically validated linkages between digital capabilities and organizational outcomes, contributing to the growing body of evidence that demonstrates how technological competencies directly influence performance metrics in modern enterprises.

To achieve these objectives, this study addresses three fundamental research questions:

1. How do emerging technologies influence the development of specific management competencies?
2. What is the impact of technology-enabled management competencies on organizational performance metrics?
3. How do organizational contextual factors moderate these relationships?

The framework recognizes four critical moderating factors that influence the effectiveness of technology-enhanced competency development: organizational culture, industry dynamism, regulatory environment, and firm size and age. These contextual factors play a crucial role in determining how effectively organizations can leverage emerging technologies for competency development and performance enhancement.

Through this comprehensive theoretical lens, we examine how specific emerging technologies influence the development of critical management competencies and investigate the impact of these technology-enabled competencies on organizational performance metrics. Furthermore, the research explores how contextual factors moderate these relationships, providing a nuanced understanding of the conditions under which digital transformation initiatives are most likely to succeed.

This paper proceeds as follows. First, we present our methodology for framework development, followed by a detailed examination of the four theoretical foundations. We then present our integrated conceptual framework, illustrating the relationships between technologies, competencies, and organizational outcomes. Finally, we discuss the implications of our findings and propose directions for future research.

2. Methodology

This research employs a conceptual framework development methodology, focusing on theoretical analysis and synthesis. Our methodological approach consists of two main phases: comprehensive literature analysis and framework development.

We conducted a systematic review of literature published in leading management and information systems journals. The review focused on four key domains: dynamic capabilities in digital contexts, knowledge-based perspectives, digital leadership, and socio-digital systems. We identified and analyzed relevant papers that form the theoretical foundation of our framework.

The framework development process employed an iterative analytical approach, integrating theoretical perspectives with emerging technology contexts. Our process involved:

1. Systematic analysis of theoretical constructs and their relationships.
2. Integration of contemporary digital transformation literature.
3. Development of framework propositions.
4. Logical verification of relationships between constructs.

The methodological framework component serves as a structural element in our conceptual model, providing systematic guidance for theoretical development. This framework emphasizes three key aspects.

First, it establishes theoretical protocols for analyzing the relationships between emerging technologies and management competencies, ensuring conceptual rigor while maintaining practical relevance. The framework adopts a multi-level perspective, considering individual, organizational, and environmental factors in the development of technology-enabled management competencies.

Second, it provides structured approaches for conceptualizing the measurement of both management competencies and organizational performance outcomes. This includes the development of theoretical measurement constructs and assessment criteria that inform future empirical research.

Finally, the framework maintains informing relationships with both management competencies and organizational performance, as illustrated in our model through dotted arrows. These relationships ensure theoretical consistency while allowing for contextual adaptation in future empirical studies.

3. Theoretical foundations

This study integrates four contemporary theoretical perspectives that provide a comprehensive framework for understanding the relationship between emerging technologies, management competencies, and organizational performance (Verhoef et al., 2021).

3.1. Dynamic Capabilities Theory in Digital Contexts

Dynamic Capabilities Theory (Teece et al., 1997; Teece, 2020), when applied to digital contexts, explains how organizations adapt, integrate, and reconfigure their competencies and resources to address the rapidly changing digital environment. The theory emphasizes three core capabilities that are particularly relevant in digital transformation: sensing (identifying technological opportunities and threats), seizing (mobilizing resources to capture value from digital initiatives), and transforming (continuously renewing organizational practices and business models in response to digital change). In digital environments, these capabilities manifest through advanced analytics, digital environmental scanning, and technology-enabled opportunity recognition (Warner, Wäger, 2019).

The application of dynamic capabilities in digital contexts highlights organizations' ability to develop and deploy technology-enabled competencies that foster competitive advantage. This includes reconfiguring organizational processes for digital operations, developing new digital competencies, and orchestrating digital resources and partnerships (Shi et al., 2021). Recent empirical evidence suggests that organizations with strong dynamic capabilities in digital contexts demonstrate superior performance in their digital transformation initiatives, particularly in areas such as platform development, ecosystem management, and digital innovation adoption.

3.2. Knowledge-Based View in Digital Environments

The Knowledge-Based View of the firm (Grant, 1996) can be extended to understand organizational knowledge management in digital environments. AI-enabled knowledge creation represents how organizations generate new insights through AI and machine learning algorithms (Faraj et al., 2018), while digital knowledge integration focuses on combining knowledge from various digital sources and systems across organizational boundaries (George et al., 2016).

Machine learning and AI capabilities enhance traditional knowledge transfer mechanisms through digital systems (Choudhury et al., 2019), including AI-powered learning platforms and automated knowledge repositories. Knowledge exploitation in digital contexts emphasizes the organization's ability to utilize digital knowledge for practical applications and value creation (Holopainen et al., 2023), building on traditional Knowledge-Based View principles while leveraging new digital capabilities for competitive advantage (Nurnaninsih et al., 2023).

3.3. Socio-Digital Systems Theory

Socio-Digital Systems Theory provides a framework for understanding the integration of human and technological elements in modern organizations (Lyytinen, Newman, 2008). Human-AI collaboration focuses on the effective partnership between human workers and AI systems (Wilson, Daugherty, 2018). This includes designing collaborative workflows, establishing trust in AI systems, and optimizing human-AI interactions. The framework's focus on developing management competencies in the face of rapid technological change is particularly relevant in the context of the ongoing digital transformation driven by Industry 4.0. As noted by Zembski and Ulewicz (2022), organizations must address the challenges faced by older employees in adapting to the requirements of this new industrial paradigm. The framework's emphasis on cultivating competencies such as digital leadership, data-driven decision making, and ethical tech governance can help bridge the digital competency gap among mature workers. Additionally, the framework's consideration of broader socio-economic factors, as discussed by Suchacka et al. (2023), underscores the need for a holistic approach to management competency development that aligns with the evolving technological and societal landscape. Digital workplace dynamics address the evolving nature of work in technology-enabled environments (Colbert et al., 2016). This involves understanding how digital tools shape work practices, communication patterns, and organizational relationships.

Techno-social integration emphasizes the alignment between technological systems and social structures within organizations. This includes considering both technical and social aspects in system design and implementation. Digital ecosystem adaptation focuses on the organization's ability to evolve and thrive within broader digital ecosystems (Wareham et al., 2014). This involves managing relationships with digital partners, adapting to ecosystem changes, and maintaining competitive advantage through ecosystem.

3.4. Digital Leadership Theory

Digital Leadership Theory addresses the unique challenges and requirements of leading organizations in the digital age (Avolio et al., 2000; Van Wart et al., 2019). Technology vision and influence relate to leaders' ability to develop and communicate compelling digital transformation strategies (Kane, 2019). This includes understanding technological trends, anticipating future developments, and inspiring organizational change. Digital change management focuses on leading organizational transformation initiatives in the context of digital innovation (Klein, 2020). This involves managing resistance to change, fostering digital adoption, and ensuring successful implementation of digital initiatives.

Virtual team leadership addresses the specific challenges of leading distributed teams through digital platforms (Malhotra et al., 2007). This includes developing virtual collaboration skills, maintaining team engagement, and ensuring effective remote communication. Digital culture cultivation involves creating and maintaining an organizational culture that

supports digital innovation and transformation (Cortellazzo et al., 2019). This includes promoting digital mindsets, encouraging experimentation, and fostering continuous learning.

4. Proposed Conceptual Framework

Based on the literature review and identified research gaps, we propose a conceptual framework for understanding the integration of cutting-edge technologies in management competency building. This framework, illustrated in Figure 1, synthesizes the key elements discussed in this paper and provides a holistic view of the relationships between technologies, competencies, and organizational outcomes.

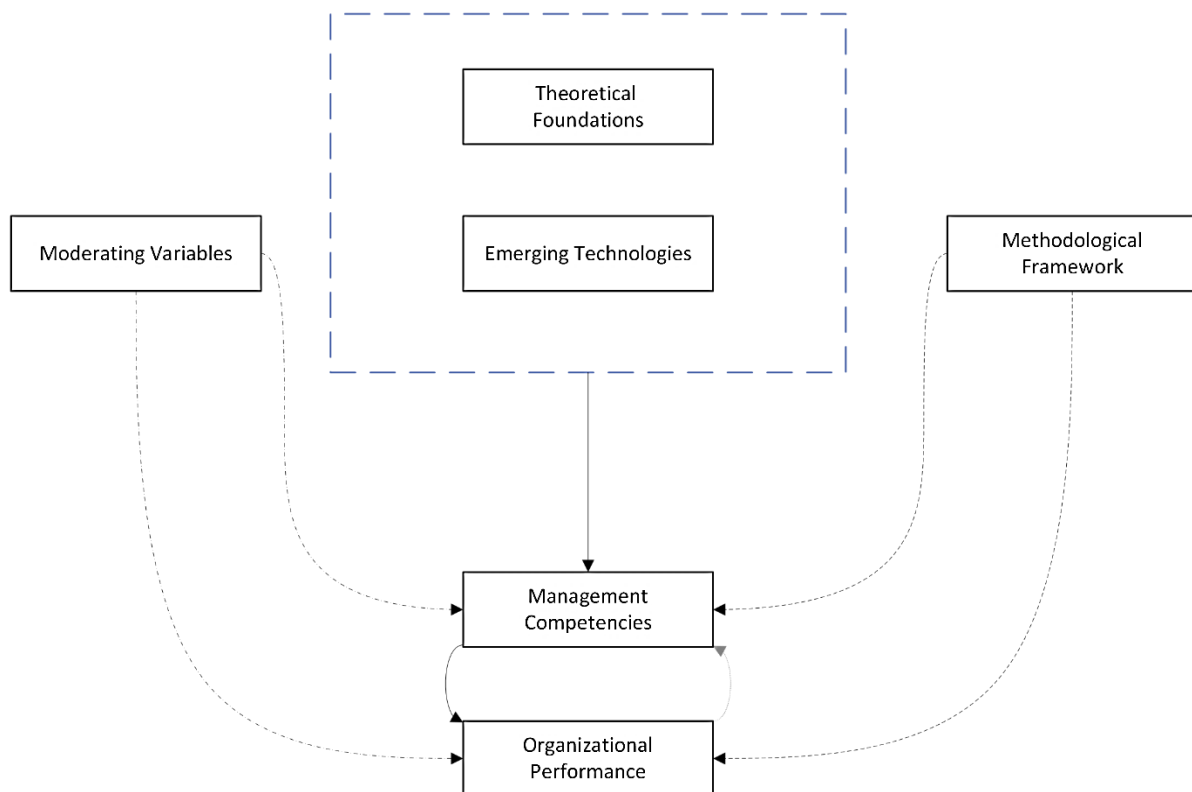


Figure 1. Conceptual Framework: Technology-Enhanced Management Competency Building.

Source: developed by authors.

The theoretical framework exhibits four distinct types of relational dynamics that collectively articulate the complex interplay between organizational elements (Figure 2).

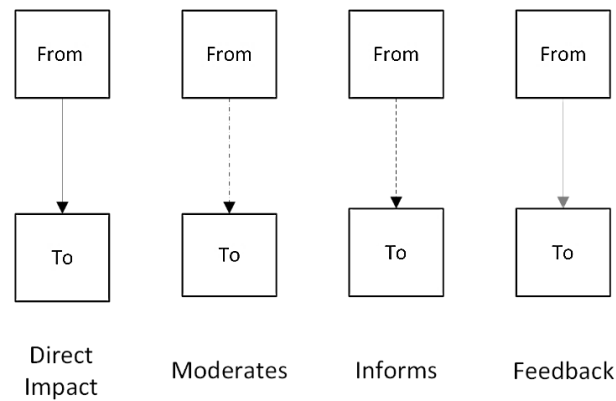


Figure 2. Types of arrows depicting framework relationships.

Source: developed by authors.

Primary causal relationships, depicted through black solid arrows, demonstrate direct influential pathways from theoretical foundations and emerging technologies to management competencies, which subsequently impact organizational performance outcomes. These relationships are moderated by contextual variables (represented by labelled and dotted arrows) such as organizational culture and industry dynamism, which function as contingency factors affecting the strength and direction of primary relationships. Concurrently, the methodological framework maintains informative relationships (indicated by dotted arrows) that provide epistemological guidance and analytical rigor to the operational components, while cybernetic feedback mechanisms (shown through grey solid arrows) facilitate organizational learning and system adaptation through iterative refinement processes. This integrated relational architecture creates a dynamic system characterized by multi-level interactions, temporal dynamics, and emergent properties that support both theoretical robustness and practical applicability within organizational contexts.

Our integrated framework synthesizes contemporary theoretical perspectives with emerging technologies and management competencies, establishing clear pathways to organizational performance. The framework reveals multiple interaction patterns: direct relationships between theoretical foundations and management competencies, moderating effects of contextual variables, and informing relationships from the methodological framework. Through systematic analysis, we propose that the development of management competencies is fundamentally shaped by the organization's ability to leverage dynamic capabilities in digital contexts, integrate knowledge-based approaches, and implement effective digital leadership practices.

The framework for building management competencies through technology brings together five key components that work together to help organizations thrive in today's digital age. At its core, the framework identifies four breakthrough technologies that are reshaping how we develop management capabilities. These technologies – AI and machine learning, Internet of Things and edge computing, blockchain and distributed ledger technologies, extended reality

(XR) and quantum computing - each bring unique strengths to help managers learn and perform better.

The landscape of modern management is being fundamentally transformed by several key technological innovations. AI and machine learning are revolutionizing organizational decision-making processes through the automation of routine management tasks, while offering sophisticated predictive analytics capabilities and AI-enabled leadership support tools. These advancements are enabling managers to focus on more strategic aspects of their roles while maintaining operational efficiency.

The Internet of Things and edge computing are facilitating unprecedented levels of real-time data collection and analysis, enabling distributed decision-making capabilities across organizational networks. This technological framework supports connected operations management and enables smart resource allocation, fundamentally changing how organizations monitor and optimize their processes.

Blockchain and distributed ledger technologies are introducing novel trust-based management mechanisms through the implementation of smart contracts and decentralized governance structures. These technologies are fostering more transparent operation systems, potentially revolutionizing how organizations handle transactions and maintain accountability.

XR is reshaping organizational interactions through enhanced virtual team collaboration capabilities and immersive training programs. This technology enables sophisticated remote operations management while significantly enhancing customer experience through innovative interfaces and interaction methods.

Quantum computing represents the next frontier in computational capabilities, promising to revolutionize complex problem-solving through advanced optimization algorithms. This emerging technology will provide secure communication systems and future-ready computing infrastructure, potentially transforming how organizations process and analyse complex data sets.

These powerful technologies directly contribute to building at least five singled out essential management competencies: digital leadership, data-driven decision making, agile strategy formulation, cross-functional orchestration and ethical tech governance. When organizations implement these technologies thoughtfully, they see managers learning more effectively, retaining skills better, and making sharper decisions. The technologies also help create more transparency throughout the organization and develop leaders who can adapt quickly to change.

Digital leadership forms the foundation of modern management competencies, focusing on guiding organizations through digital transformation and fostering a culture of innovation and technological adaptation. This competency enables leaders to navigate the rapidly evolving digital landscape while empowering teams to embrace new technologies and ways of working.

Data-driven decision making represents the analytical backbone of contemporary management, where leaders leverage insights from complex data sets to inform strategic choices. This approach ensures that decisions are grounded in empirical evidence rather than merely intuition or past experiences.

Agile strategy formulation reflects the need for flexible and responsive planning in today's fast-paced business environment. This competency enables managers to develop and adapt strategies quickly in response to market changes, while maintaining alignment with long-term organizational goals.

Cross-functional orchestration emphasizes the ability to coordinate and integrate diverse teams and departments effectively. This skill is crucial for breaking down silos and fostering collaboration across different organizational units, ensuring seamless execution of projects and initiatives.

Ethical tech governance rounds out the essential management competencies by focusing on responsible technology implementation and use. This competency involves establishing frameworks for ethical decision-making in technology adoption, ensuring privacy, security, and social responsibility while driving technological innovation.

When managers develop these enhanced competencies, organizations typically see five major benefits, however, this number is not exhaustive. They include innovation output, operational efficiency, market responsiveness, sustainability metrics and financial performance.

Innovation output serves as a critical indicator of organizational performance, measuring an organization's ability to generate and implement new ideas, products, services, and processes. This metric reflects the company's creative capacity and its success in transforming innovative concepts into tangible market offerings that create value.

Operational efficiency demonstrates how effectively an organization utilizes its resources and optimizes its processes to deliver maximum output with minimal waste. This performance measure encompasses productivity levels, resource utilization, process streamlining, and the overall effectiveness of operational systems in achieving organizational goals.

Market responsiveness illustrates an organization's agility in adapting to changing market conditions and meeting evolving customer needs. This metric evaluates how quickly and effectively the organization can respond to market shifts, competitor actions, and emerging opportunities while maintaining customer satisfaction and market position.

Sustainability metrics provide insight into an organization's long-term viability and its impact on environmental, social, and governance (ESG) factors. These measurements assess the organization's commitment to sustainable practices, social responsibility, and ethical governance, reflecting its contribution to broader societal goals while ensuring business continuity.

Financial performance represents the traditional cornerstone of organizational success, encompassing key indicators such as revenue growth, profitability, return on investment, and market share. This fundamental metric provides a quantitative assessment of the

organization's economic health and its ability to generate value for stakeholders while maintaining financial sustainability.

Methodological framework represents a comprehensive and systematically integrated approach to understanding, implementing, and evaluating management practices within organizational contexts. This multifaceted framework encompasses various research paradigms, including quantitative and qualitative methodologies, mixed-method approaches, and systematic protocols for data collection and analysis, all of which are fundamental to establishing empirically validated management practices and organizational interventions. Furthermore, it incorporates established theoretical constructs, validated assessment instruments, and evidence-based implementation strategies that facilitate the rigorous examination of management competencies and their subsequent impact on organizational performance metrics.

In the contemporary organizational landscape, the methodological framework serves as a crucial nexus between theoretical postulations and practical applications, providing researchers and practitioners with structured approaches for investigating the complex interrelationships between management competencies and organizational outcomes. This framework not only delineates the procedural aspects of management research and practice but also establishes the epistemological foundations necessary for advancing the field through systematic inquiry, empirical validation, and theoretical development. The framework's integration with both management competencies and organizational performance indicators underscores its pivotal role in fostering evidence-based management practices while simultaneously contributing to the scholarly discourse on organizational effectiveness and strategic management.

The framework recognizes at least four important factors that influence how well this technology-enhanced learning works in practice. They are organizational culture, industry dynamism, regulatory environment and firm size and age. Organizational culture acts as a crucial moderating variable that shapes how effectively management competencies translate into organizational performance. This variable encompasses the shared values, beliefs, and behaviors within an organization, influencing how initiatives are implemented, how changes are received, and how effectively teams collaborate towards common goals. The strength and nature of the organizational culture can either amplify or diminish the impact of management practices.

Industry dynamism represents the rate and intensity of change within a specific business sector, significantly moderating the relationship between management practices and organizational outcomes. This variable affects how quickly organizations need to adapt their strategies, how relevant certain competencies become, and how different performance metrics should be weighted in different industry contexts. Industries with high dynamism may require different management approaches compared to more stable sectors.

Regulatory environment serves as a critical external moderating variable that influences how organizations can implement their strategies and measure their performance. This factor encompasses the legal frameworks, compliance requirements, and governmental policies that organizations must navigate. The strictness or leniency of regulatory requirements can significantly impact the relationship between management practices and organizational effectiveness.

Firm size and age moderate how management competencies influence organizational performance by affecting the complexity of operations, available resources, and established practices. These organizational characteristics influence the implementation of new initiatives, the ability to change direction quickly, and the effectiveness of different management approaches. Larger, more established firms may face different challenges and opportunities compared to smaller or younger organizations, affecting how management competencies translate into performance outcomes.

The framework posits that cutting-edge technologies directly influence the development of management competencies. Each technology can potentially contribute to multiple competencies. These enhanced competencies, in turn, lead to positive organizational outcomes. For instance, improved skill retention and enhanced decision-making can contribute to overall improved performance and increased agility. The framework also highlights the role of theoretical foundations, organizational context, and ethical considerations in shaping the competency building process. These factors can influence how technologies are implemented and how effectively they contribute to competency development.

5. Discussion and Conclusion

The integrated framework developed in this research offers several significant theoretical and practical contributions to understanding technology-enabled management competencies and their impact on organizational performance. Our analysis reveals complex interrelationships between emerging technologies, management competencies, and performance outcomes, building upon established research in digital transformation.

From a theoretical perspective, this research extends existing understanding in several key ways. First, it demonstrates how dynamic capabilities serve as fundamental mechanisms through which organizations develop and deploy technology-enabled management competencies. Second, the integration of knowledge-based perspectives provides new insights into how organizations create and leverage digital knowledge for competitive advantage. Third, our framework illuminates the critical role of socio-technical systems in shaping the effectiveness of management competencies in digital environments.

The practical implications align with recent research on digital transformation challenges, suggesting that successful digital transformation requires careful attention to both technological adoption and competency development. Organizations implementing digital transformation initiatives can utilize this framework to systematically develop management competencies aligned with emerging technologies, addressing known challenges in digital transformation implementation.

This research contributes to both the theoretical understanding and practical implementation of technology-enabled management competencies. Our framework builds upon established digital transformation research while extending it through the integration of contemporary theoretical perspectives with emerging technologies and organizational performance metrics.

The framework's primary contribution lies in its systematic integration of theoretical foundations, emerging technologies, and management competencies, while considering the crucial role of contextual factors and methodological approaches. This integration provides organizations with a structured approach to developing management competencies in the digital age, addressing gaps identified in recent literature.

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References

1. Artyukhov, A., Wołowiec, T., Artyukhova, N., Bogacki, S., Vasylieva, T. (2024). SDG 4, Academic Integrity and Artificial Intelligence: Clash or Win-Win Cooperation? *Sustainability*, Vol. 16, No. 19. Multidisciplinary Digital Publishing Institute, pp. 8483-8483, doi: <https://doi.org/10.3390/su16198483>.
2. Avolio, B.J., Kahai, S. Dodge, G.E. (2000). E-leadership: Implications for theory, research, and practice. *The Leadership Quarterly*, Vol. 11 No. 4, pp. 615-668, doi: [https://doi.org/10.1016/s1048-9843\(00\)00062-x](https://doi.org/10.1016/s1048-9843(00)00062-x).
3. Choudhury, P., Wang, D., Carlson, N.A., Khanna, T. (2019). Machine learning approaches to facial and text analysis: Discovering CEO oral communication styles. *Strategic Management Journal*, Vol. 40, No. 11, pp. 1705-1732, doi: <https://doi.org/10.1002/smj.3067>.

4. Colbert, A., Yee, N., George, G. (2016). The Digital Workforce and the Workplace of the Future. *Academy of Management Journal*, Vol. 59 No. 3, pp. 731-739.
5. Cortellazzo, L., Bruni, E., Zampieri, R. (2019). The Role of Leadership in a Digitalized World: A Review. *Frontiers in Psychology*, Vol. 10, No. 1, pp. 1-21, doi: <https://doi.org/10.3389/fpsyg.2019.01938>.
6. Faraj, S., Pachidi, S., Sayegh, K. (2018). Working and organizing in the age of the learning algorithm. *Information and Organization*, Vol. 28 No. 1, pp. 62-70, doi: <https://doi.org/10.1016/j.infoandorg.2018.02.005>.
7. George, G., Osinga, E.C., Lavie, D., Scott, B.A. (2016). Big Data and Data Science Methods for Management Research. *Academy of Management Journal*, Vol. 59, No. 5, pp. 1493-1507, doi: <https://doi.org/10.5465/amj.2016.4005>.
8. Grant, R.M. (1996). Toward a Knowledge-Based Theory of the Firm. *Strategic Management Journal*, Vol. 17, No. S2, pp. 109-122.
9. Holopainen, M., Saunila, M., Ukko, J. (2023). Value creation paths of organizations undergoing digital transformation. *Knowledge and Process Management*, Vol. 30, No. 2, doi: <https://doi.org/10.1002/kpm.1745>.
10. Kane, G. (2019). The Technology Fallacy: People Are the Real Key to Digital Transformation. *Research-Technology Management*, Vol. 62, No. 6, pp. 44-49.
11. Kane, G., Palmer, D., Phillips, A., Kiron, D., Buckley, N. (2015). Strategy, Not Technology, Drives Digital Transformation. *MIT Sloan Management Review and Deloitte University Press*.
12. Klein, M. (2020). Leadership characteristics in the era of digital transformation. *Business & Management Studies: An International Journal*, Vol. 8, No. 1, pp. 883-902, doi: <https://doi.org/10.15295/bmij.v8i1.1441>.
13. Kuzior, A., Sira, M., Brożek, P. (2023). New technologies as tools supporting innovation management. *Zeszyty Naukowe Organizacja i Zarządzanie*, No. 188. Politechnika Śląska, doi: <https://doi.org/10.29119/1641-3466.2023.188.16>.
14. Kuzior, A., Sobotka, B., Postrzednik-Lotko, K.A., Smółka-Franke, B. (2023). Managing Competences of Generation Y and Z in the Opinion of the Employees in the Modern Business Services Sector in Poland in the Post-Pandemic Period. *Sustainability*, Vol. 15, No. 20, p. 14925, doi: <https://doi.org/10.3390/su152014925>.
15. Kuzior, A., Zozul'ak, J., Balahurovska, I. (2023). The evolution of leadership styles during the industrial development of society. *Zeszyty Naukowe Organizacja i Zarządzanie*, No. 188. Politechnika Śląska, doi: <https://doi.org/10.29119/1641-3466.2023.188.17>.
16. Lyeonov, S., Draskovic, V., Kubaščíková, Z., Fenyves, V. (2024). Artificial intelligence and machine learning in combating illegal financial operations: Bibliometric analysis. *Human Technology*, Vol. 20, No. 2. University of Jyväskylä, pp. 325-360, doi: <https://doi.org/10.14254/1795-6889.2024.20-2.5>.

17. Lyu, J. (2024). How does digital leadership improve organizational sustainability: Theory and evidence. *Journal of Cleaner Production*, Vol. 434, Elsevier BV, pp. 140148-140148, doi: <https://doi.org/10.1016/j.jclepro.2023.140148>.
18. Lyytinen, K., Newman, M. (2008). Explaining information systems change: a punctuated socio-technical change model. *European Journal of Information Systems*, Vol. 17, No. 6, pp. 589-613, doi: <https://doi.org/10.1057/ejis.2008.50>.
19. Malhotra, A., Majchrzak, A., Rosen, B. (2007). Leading virtual teams. *Academy of Management Perspectives*, Vol. 21, No. 1, pp. 60-70, doi: <https://doi.org/10.5465/amp.2007.24286164>.
20. Nurnaninsih, A., Mukhtar, B.A., Muthmainah, H.N. (2023). Knowledge Management in the Digital Age: Harnessing Information and Innovation with Knowledge Management Systems. *The Eastasouth Journal of Information System and Computer Science*, Vol. 1, No. 1, pp. 25-34, doi: <https://doi.org/10.58812/esiscs.v1i01.131>.
21. Sambamurthy, V., Bharadwaj, A., Grover, V. (2003). Shaping Agility through Digital Options: Reconceptualizing the Role of Information Technology in Contemporary Firms. *MIS Quarterly*, Vol. 27, No. 2, p. 237, doi: <https://doi.org/10.2307/30036530>.
22. Schiuma, G., Schettini, E., Santarsiero, F., Carlucci, D. (2021). The transformative leadership compass: six competencies for digital transformation entrepreneurship. *International Journal of Entrepreneurial Behavior & Research*, Vol. 28, No. 5, pp. 1273-1291, doi: <https://doi.org/10.1108/IJEBr-01-2021-0087>.
23. Shi, W., Xia, C., Meyer-Doyle, P. (2021). Institutional Investor Activism and Employee Safety: The Role of Activist and Board Political Ideology. *Organization Science*, Vol. 33, No. 6, doi: <https://doi.org/10.1287/orsc.2021.1542>.
24. Strielkowski, W., Samoilikova, A., Smutka, L., Civiń, L., Lieonov, S. (2022). Dominant trends in intersectoral research on funding innovation in business companies: A bibliometric analysis approach. *Journal of Innovation & Knowledge*, Vol. 7, No. 4, p. 100271, doi: <https://doi.org/10.1016/j.jik.2022.100271>.
25. Suchacka, M., Pabian, A.M., Ulewicz, R. (2023). Industry 4.0 and socio-economic evolution. *Polish Journal of Management Studies*, Vol. 28, No. 1, pp. 311-329, doi: <https://doi.org/10.17512/pjms.2023.28.1.18>.
26. Teece, D.J. (2018). Business models and dynamic capabilities. *Long Range Planning*, Vol. 51, No. 1, pp. 40-49, doi: <https://doi.org/10.1016/j.lrp.2017.06.007>.
27. Teece, D.J. (2020). Hand in Glove: Open Innovation and the Dynamic Capabilities Framework. *Strategic Management Review*, Vol. 1, No. 2, pp. 233-253, doi: <https://doi.org/10.1561/111.00000010>.
28. Teece, D.J., Pisano, G., Shuen, A. (1997). Dynamic Capabilities and Strategic Management. *Strategic Management Journal*, Vol. 18, No. 7, pp. 509-533.

29. Van Wart, M., Roman, A., Wang, X., Liu, C. (2019). Operationalizing the definition of e-leadership: identifying the elements of e-leadership. *International Review of Administrative Sciences*, Vol. 85, No. 1, pp. 80-97.
30. Vasylieva, T., Witczak-Smolnik, W., Tiutiunyk, I., Filep, B. (2023). Social and economic determinants of quality of life: Case of European countries. *Economics & Sociology*, Vol. 16, No. 4. Szczecin: Centre of Sociological Research, pp. 289-308, doi: <https://doi.org/10.14254/2071-789x.2023/16-4/14>.
31. Verhoef, P.C., Broekhuizen, T., Bart, Y., Bhattacharya, A., Qi Dong, J., Fabian, N., Haenlein, M. (2021). Digital transformation: a Multidisciplinary Reflection and Research Agenda. *Journal of Business Research*, Vol. 122, No. 122, pp. 889-901, doi: <https://doi.org/10.1016/j.jbusres.2019.09.022>.
32. Vial, G. (2019). Understanding Digital transformation: a Review and a Research Agenda. *The Journal of Strategic Information Systems*, Vol. 28, No. 2, pp. 118-144, doi: <https://doi.org/10.1016/j.jsis.2019.01.003>.
33. Wareham, J., Fox, P.B., Cano Giner, J.L. (2014). Technology Ecosystem Governance. *Organization Science*, Vol. 25, No. 4, pp. 1195-1215, doi: <https://doi.org/10.1287/orsc.2014.0895>.
34. Warner, K.S.R., Wäger, M. (2019). Building Dynamic Capabilities for Digital transformation: an Ongoing Process of Strategic Renewal. *Long Range Planning*, Vol. 52, No. 3, pp. 326-349, doi: <https://doi.org/10.1016/j.lrp.2018.12.001>.
35. Wilson, H.J., Daugherty, P.R. (2018). Collaborative Intelligence: Humans and AI Are Joining Forces. *Harvard Business Review*, July, available at: <https://hbr.org/2018/07/collaborative-intelligence-humans-and-ai-are-joining-forces>.
36. Zembski, S., Ulewicz, R. (2022). Managing the process of adjusting the competences of employees aged forty or over to the requirements of industry 4.0. *Technical Transactions*, No. 1. Wydawnictwo Uniwersytetu Jagiellońskiego, pp. 1-13, doi: <https://doi.org/10.37705/techtrans/e2022015>.

CONSUMER PREFERENCES IN THE CONTEXT OF POSSIBLE ORGANIZATION OF ENOTOURISM SERVICES IN CENTRAL POLAND

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Purpose: The aim of the research was to determine consumers' expectations regarding enotourism, examine the possibilities for its development in central Poland, and explore strategies to enhance profitability for vineyard owners.

Methodology: The study was conducted in 2024 using quantitative PAPI (paper and personal interview) and CAWI (computer-assisted web interview) methods among Polish residents. The representative sample was 1067 people. A total 984 correctly completed surveys which were used for analysis. The questionnaire consisted of three parts: general questions on the use of enotourism services, knowledge and use of services in central Poland and demographic information. using survey forms with 984 participants from 16 voivodeships across Poland. The questionnaire covered three parts: general enotourism behaviors, specific knowledge and demographic data. The model's dependent variable was the frequency of visiting enotourism sites in Poland. Due to its dichotomous nature a logistic regression model was applied, including only statistically significant variables. Model quality was evaluated using the Hosmer-Lemeshow test and C-statistics.

Findings: The positive perception of central Poland as an enotourism destination strongly correlates with visitors' frequency of vineyards visits. Central Poland has the potential to become an important enotourism center; however, this requires a well-organized, strategic approach and coordination of various stakeholder activities.

Originality/value: The article introduces a fresh perspective on the potential for enotourism development in central Poland, highlighting opportunities from climate change and shifting wine growing zones. It uniquely analyzes specific factors attracting enotourists, such as prior visitor experience and interest in local wine production, within a region without strong wine traditions. The article is aimed at tourism policymakers, vineyard owners, local authorities and

tourism development organizations. It also serves research in enotourism and those interested in the tourism potential linked to horticultural adaptation to changing climate conditions.

Keywords: enotourism, vineyards, central Poland.

Category of the paper: Research paper.

1. Introduction

In recent years, sustainable development issues have become a key element in vineyard management around the world, including in Poland. Sustainable development of vineyards is a key element of wine tourism in Poland, contributing to environmental protection and promoting responsible agricultural practices. By using ecological viticulture practices, such as reducing the use of pesticides, using natural fertilizers, and managing water, winemakers can minimize the negative impact on the environment while improving the quality of their products (Vinci et al., 2022). Polish vineyards are increasingly implementing ecological cultivation methods, such as minimizing the use of pesticides and artificial fertilizers, which contributes to maintaining biodiversity and soil health (Nowak, 2022). For example, Winnica Turnau (West Pomeranian Voivodeship) and Winnica Srebrna Góra (Lesser Poland Voivodeship) use natural preparations and composting, which allows maintaining a healthy ecosystem around the vineyards (Kowalski, 2021).

Additionally, vineyards engage in educational activities by organizing workshops and tastings that promote ecological awareness among tourists (Wiśniewski, 2020). Educational tours are also often held in vineyards, during which visitors can learn about sustainable viticulture practices and the wine production process (Zielińska, 2019). The Adoria vineyard (Lower Silesian Voivodeship), for example, offers special educational programs for schools and tourists promoting ecological wine production methods (Grabowski, 2018). Sustainable practices also include the use of renewable energy and water resources management, which helps reduce the carbon footprint of wine production (Lewandowski, 2023). Many vineyards, such as Winnica Płochockich (Świętokrzyskie Voivodeship), invest in solar panels and rainwater recovery systems, which significantly reduces their impact on the environment (Szymańska, 2021). The introduction of sustainable viticulture practices also attracts tourists who are increasingly ecologically aware and seek authentic wine experiences, including wine tasting, education on viticulture, and relaxation in picturesque vineyard landscapes (Mariani et al., 2022). Moreover, the development of wine tourism supports the local economy by generating additional income for winemakers and local tourism-related enterprises (Gómez et al., 2019). Winemakers who invest in sustainable practices can also count on the loyalty of customers who value products made with respect for the environment and tradition (Pomarici, et al., 2017). Thanks to these initiatives, wine tourism in Poland is becoming not only a tourist attraction but also an example of the integration between agricultural activities and

environmental protection, which has a significant impact on local communities and the economy (Majewski, 2022). Sustainability is not only a matter of environmental protection but also an approach that takes into account the economic and social aspects of wine production. In Poland, as in other European countries, vineyards are exposed to climate change, which may have a significant impact on the quality and quantity of the harvest (Hannah et al., 2013). For this reason, farmers are increasingly using organic farming practices, limiting the use of plant protection products while promoting natural, ecological methods of plant protection (Kowalski, 2021; Nowak, 2022).

Tourism as a dynamic phenomenon is constantly evolving under the influence of various social, cultural, economic, political, as well as natural and technological factors (Bibiciou et al., 2013). These changes have contributed to an increase in interest in new types of tourism, among which enotourism holds a special place. Due to its specificity, enotourism, at least on a small scale, can also be considered a good example of sustainable tourism (Kowalczyk, 2010). Wine tourism has long existed in parts of Europe and North America, and in Australia it has developed as a distinct tourism product since the early 1980s (Weaver et al., 2002; Yuan et al., 2005; McNamara et al., 2015). Enotourism has always been associated with "old world" regions, having a profound impact on their cultural and regional development (Gomez et al., 2019; Vazquez, 2021). In these countries, wine production is abundant and dominates most social interactions and social life (Zainurin et al., 2022). In Europe, enotourism was often associated with official wine trails and roads. Formal links between tourism and wine, especially through the creation of wine routes, have existed since the first half of the century and have expanded significantly in recent times (Hall et al., 2000). Recently, "new world" and developing countries have also joined this trend, and wine consumption and related products such as enotourism, wine festivals, and wine routes are starting to become embedded in their lifestyles (Singh et al., 2020; Yadav et al., 2022). The world of wine is becoming more and more popular, starting from getting to know the vineyard, wine production and gaining knowledge about grape varieties and their characteristics, as well as the bottling process (Fuentez-Fernandez et al., 2022). Well known as enotourism, vinotourism or wine tourism, it has many definitions, dimensions and meanings and is a relatively new form of tourism that has developed in wine-producing countries and/or regions (Bibiciou et al., 2013). The definition of wine tourism is not uniform because it can be analyzed from different perspectives, such as marketing or traveler motivation (Jaykumar, Fukey, 2014). According to Bunghez (2022), it involves visiting vineyards and vineyards, ending with wine tasting, which also includes a presentation of the wine production route, from growing and harvesting grapes to bottling and aging processes. It combines wine, food, culture and experiences related to tasting wine and its production method, which has great potential for wine-producing areas (Trigo, Silva, 2022). Wine tourism is perceived as a sensory experience that offers various attractions for visitors, such as a lifestyle experience, the pleasure of tasting or participation in festivals, as highlighted by the studies of Hall and Macions (1998), Hall et al. (2000), Charters and Ali-Knight (2002)

and Getz and Brown (2006). Anastasiadis and Alebaki (2021) defined it as a new form of tourism encompassing a wide range of activities and infrastructure. As noted by Carlsen and Boksberger (2015), wine tourism is based on complex interactions between tourists, wine products, the adapted winery environment, management systems and other elements of the winery. Byrd et al. (2015) succinctly defined it as a vineyard tour during which tourists experience what they love about wine. The three main elements of wine tourism are: visits of wine connoisseurs and buyers, visits to vineyards and wine routes (Olaru, 2012). Telfer (2001) identified three components that constitute a winescape: the presence of vineyards, the production activities of the vineyards, and the vineyards where the wine is produced and stored. Wine tourism research suggests and promotes the idea that food and wine can be, and often are, the primary reason for traveling to a particular region and not necessarily the travel activity (Bibiciou, 2013).

Getz and Brown (2006) indicated that the main goals of tourist' trips are attractive scenery, pleasant climate, affordable accommodation, ease of obtaining information, and wine routes that are well-marked and offer a variety of attractions. Wine tourism should focus on experiences and activities related to wine tasting and vineyard visits (Ribero Santos et al., 2019). Enotourism should offer unique and authentic tourist experiences that need to be more personalized and diverse. Wine tourism can play an important role in the economic development of wine regions while consolidating them as tourist destinations (Lopez-Guzman et al., 2014).

The combination of wine and tourism can bring significant economic revenues to wine-producing regions (Bruwer, 2003). Wine tourism industry employees believe that wine tourism effectively improves the image of a wine brand and contributes to the construction of the infrastructure of tourist destinations (Baker, 2016). Wine tourism brings direct economic value to regions by supporting local producer networks, including not only wine producers, but also regional food producers, hospitality, and arts and crafts (Telfer, 2001; Founatin, 2014; Serra et al., 2021). At the level of an individual producer, it is difficult to estimate exact income, but wine tourism increases the number of revenue streams and direct sales (Carlsen, Dowling, 1998; Remenova et al., 2019; Smyczek et al., 2020). The economic role of wine tourism is based on increasing the importance of the brand, which may concern regional brands as well as consumer loyalty and long-term repeat visits and purchases (Alonso, Liu, 2012; Tafel, Szolonki, 2021). In their study, Szolnoki and Tafel (2021) showed that the direct and indirect impact of wine tourism in German wine regions amounted to EUR 5 billion in 2019. Dreyer (2019) described the growing activity of wine tourism in the last decade and noted the versatility of wine tourism in Germany. According to New Zealand government data, an average of 13% of international holiday tourists visiting the country visit vineyards or participate in wine tourism activities each year, equating to more than 200,000 people per year (Zealand, 2014). This market is lucrative as international wine tourism tourists spend an average of NZ\$ 3700, compared to an average spend of NZ\$ 2800 for all visitors (Baiurd et al., 2018).

Importantly, 94% of international wine tourists are independent travelers, which strengthens their ability to travel to rural regions, and their stays are significantly longer (average 18.6 days) compared to the average for all visitors of 14.4 days (Zealand, 2014). In recent years, with China's rapid economic development, visiting vineyards has become a new type of tourism in China (Ye et al., 2014). However, from the perspective of the wine tourism industry as a whole, it is still in its infancy with enormous potential for future development (Smyczek, 2020). The Third Global Wine Tourism Conference (World Tourism Organization, 2016) indicated that wine tourism is still an immature market that requires more in-depth research to better understand its future. Viticulture is often seen as an extremely important factor for regional development in rural areas due to its contribution to regional branding and significant employment opportunities (Hall, Gossling, 2016). This perception is reinforced both by direct aspects, i.e. visits to vineyards, and indirect aspects, for example, purchasing local wine and food in restaurants, which highlights the role of viticulture in tourism in such regions (Baiurd et al., 2018). Value for wine tourists is created by aspects related to the product, such as: the quality of the wine offered, the attractiveness of the landscape (Dodd, Gustafon, 1997), the winery, the historical context of the wine region and the regional cultural heritage (Charters et al., 2009). Nowadays, consumers increasingly pay attention to local products. This is due to the trend of returning to using products from natural raw materials, including food, and activities aimed at implementing the idea of sustainable development in everyday life (Kołodziej, 2022). Thanh and Kirova (2018) analyzed 825 TripAdvisor reviews using an economic experience model and found that winery education is the dominant aspect in wine tourists' experiences, in addition to entertainment. Nella and Christou (2021) found that a winery visit includes the experiential value of learning about wine and its production, which attracts a large number of tourists to wineries. Wine tourism is considered a sustainable form of spending free time, which is due to its inextricable links with “nature, know-how and economic activity” (Pulpon, Ruiz, 2019). UNWTO (2016) recognized wine tourism as a key element of gastronomic tourism that can play a multi-faceted role in sustainable rural development, promoting destination heritage, natural resource conservation, income generation and social benefits, especially for less advantaged regions.

In the face of global climate change, the tourism sector in Europe is experiencing significant transformations. Climate change directly affects this sector, which is particularly visible in the predictions of a decline in tourist activity in southern Europe and an increase in the northern and continental parts after 2050 (Sottini et al., 2021). As research by Droulia and Charalampopoulos (2021) indicates, the expansion of vineyards into new areas is changing the traditional geography of wine-growing areas. In northern regions, new opportunities are emerging for viticulture, which was previously considered risky (Fraga et al., 2013). They create opportunities to introduce hybrid, more resistant and durable grape varieties adapted to more difficult conditions (Myśliwiec, 1992; Schernewski, 2011; Bosak, 2013; Myga-Piątek, Rahmonov, 2018; Johnson, Robinson, 2019). In turn, according to Maciejczak

and Mikciuk (2018), changes in the crop calendar caused by climate change may affect the profitability of the enotourism industry, and the increased frequency of extreme weather phenomena such as droughts and heat waves may create a risk for sustainable wine production, as noted by Szwed et al. (2010). The increase in global temperature may contribute to changes in traditional wine regions, creating new alternatives, which in turn may affect tourist satisfaction and change demand patterns in the enotourism sector (Brzózka, Jaczewski, 2016; Marcinkowski, Pniewski, 2018). New wine regions emerging in northern Europe may attract tourists by changing the tourism landscape (Santos et al., 2020). Additionally, changes in the seasonal distribution and quality of wine encourage producers to rethink their cultivation strategies, which is key to maintaining competitiveness and attracting tourists (Romanowicz et al., 2016). Poland is not a typical wine country. Both in terms of vineyard area, wine production, and wine consumption, it is below the world average (Jeziorska-Biel et al., 2021). Although it was not popular before, it is gaining in importance. The increase in the number of vineyards and the development of enotourism services may transform this niche sector of tourism into a significant market segment (Bosak, 2013; Kołek, 2023). Similarly, in the northern New York region, the increase in average annual temperatures creates challenges for wine producers, which highlights the need to adapt cropping strategies to changing climatic conditions (Kundzewicz et al., 2018). Research by Dec and Krupa (2014) indicates that enotourism in regions rich in vineyards is becoming an important direction of development for small rural farms, especially since a significant percentage of tourists buy wine produced on-site.

Running a vineyard in Polish conditions can be a challenge in terms of profitability due to both the climate and the specifics of the market (Maciejczak, Mikciuk, 2018). Despite the growing number of vineyards, Poland still faces issues related to low production scale and significant competition on the international market (Szumelda, 2019). Wine production requires substantial financial investments in vineyard development, as well as appropriate adaptation of cultivation methods to local climatic conditions, which may be less favourable than in traditional wine-producing regions (Sidorkiewicz, 2023). The climate in Poland, characterised by cold winters and short summers with moderate temperatures, presents difficulties for Polish winemakers in cultivating grapevines, which are particularly sensitive to weather conditions (Koźmiński et al., 2020). In recent years, climate change may create new opportunities for winemaking in Poland, but at the same time, it necessitates the implementation of appropriate adaptive strategies to minimise the risks associated with unfavourable production conditions (Maciejczak, Mikciuk, 2018). In addition to climate challenges, the Polish wine market is also characterised by specific consumer demands and low awareness of local wines, which further complicates the development of this industry (Trestini et al., 2020). Despite the growing interest in regional wines, Polish winemakers have to compete with imported wines that dominate the market (Wójcik, 2022). Therefore, to increase profitability, Polish vineyards need to invest in

marketing and consumer education while developing the unique qualities of their products that can attract the attention of discerning customers (Kunicka-Styczyńska et al., 2016).

Vine is grown in various regions of Poland. Generally, the first larger vineyards began to develop in the 1980s in the Podkarpackie Voivodeship and in the Lubuskie and Lesser Poland Voivodeships. These regions, as Smogór (2012) pointed out, have been the main wine-growing areas in the country for years. However, according to the latest KOWR data (2024), in the 2023/24 economic year, the largest area under vines (covered by the register, intended for commercial production) was still located in the Lesser Poland Voivodeship (122 ha), Podkarpackie Voivodeship (85 ha), Lower Silesia (52 ha) and Lubuskie (51 ha). However, in three voivodeships covering central Poland, i.e. Masovian, Łódź and Świętokrzyskie voivodeships, the total area of vineyards covered 67 ha. For comparison, in the 2017/18 marketing year, as Olewnicki (2018) pointed out, in these voivodeships it was 33.4 ha. Within a few years, it doubled. Therefore, it is a promising region not only in terms of the development of winemaking itself, but also in terms of the possibility of developing enotourism.

The Podkarpackie region in Poland is an example of a developing model of small wine farms that combine the production of high-quality wines with agritourism offers. This area is characterized by a significant number of vineyards, which makes it the nucleus of a real wine region (Olszewski, 2013). According to the Polish Tourist Organization (2024), the enotourism offer in Poland has so far been poorly recognizable, therefore it was necessary to highlight it as part of promotional activities. The Polish offer of enotourism trips was also limited, with the dominant role of importers and wine sellers, which resulted from the emerging market for this type of services (Kosmaczewska, 2006). However, research by Wójcik (2022) showed that wine production in Poland has increased as much as 43 times over 13 years (wine years 2009-2022), which contributes to the increase in wine consumption and can potentially support the development of wine tourism. Wine tourism in Poland is gaining popularity and becoming an increasingly important tourism segment, with the Podkarpackie region as the leading wine region in the country (Krupa, Stokłosa, 2015). Despite various obstacles, the first groups of enotourist have visited Polish wine farms since 2008, which proves the effectiveness of ongoing efforts to revive wine traditions in regions such as Poscarpathia, Lesser Poland and western Poland by supporting the establishment of small vineyards and the development of grape processing on agricultural and agritourism farms (Wrzochalska, 2001). There is an increase in the number of vineyards, companies offering important development factors is the activity of organizations and associations supporting viticulture and establishing vineyards, which translates into an increase in the skills of vineyard owners in the fields of viticulture and wine production. The promotion of Polish winemaking, including the organization of wine festivals, also plays an important role in their activities.

However, enotourism, or wine tourism, is a key element in supporting vineyard revenues and can significantly enhance their profitability (Jesiotr, Szymańska, 2016). Enotourism in Poland is developing dynamically, with vineyards increasingly incorporating tourism offerings

as an integral part of their operations (Bunghez, 2022). Sokół (2015) research highlights opportunities for the development of enotourism in Poland, emphasising the growing interest in winemaking within the country. This view is also supported by Dominik (2016), who explains that the increasing interest in wine in Poland stems from Poles adopting Western lifestyles, which translates into a rise in the consumption of this beverage. Moreover, studies show that integrating tourism activities with agricultural operations can lead to better resource utilisation and diversification of income sources, which is particularly important in the context of changing economic and climatic conditions (Seo, 2010; Luo et al., 2023).

2. Materials and methods

2.1. Data collection

The analyzes presented in this work were carried out using the results of empirical research, and their aim was to determine the factors (determinants of more frequent (regular) use of enotourism services, both in Poland in general and in central Poland in detail. The research was carried out in 2024 using quantitative PAPI methods (paper and pen personal interview) and CAWI (computer assisted web interview), among the inhabitants of Poland. In accordance with the principles of selecting a representative sample for survey research, with a confidence level of $\alpha = 0.95$ and a fraction size of 0.5 (standard value) and assumed maximum error of 3.0%, the representative sample is 1067 (with the population of Poland provided by the Central Statistical Office at the beginning of 2024 being 37.6 million people). The total number of surveys indicated above was collected, and after verifying the correctness of their completion, 984 were used for further analyses.

The questionnaire consisted of three parts, the first - containing questions regarding, among others: general use of enotourism services by respondents both in Poland and abroad, motives for enotourism trips, time spent in vineyards, amount of financial resources allocated to enotourism services. The second part concerned the respondents' knowledge and use of enotourism services located in central Poland. According to the NUTS classification of Polish macroregions, until 2016 the central part of Poland included the Masovian and Łódź voivodeships. However, after the classification was changed in 2017. the Świętokrzyskie Voivodeship was included in the central region, while the Masovian macroregion was separated as a separate region. This research is part of a larger project, including, apart from enotourism itself, research on climate change over a longer period of time, therefore all three above-mentioned voivodeships are included in the Central Poland region, despite changes in NUTS classifications in individual years. Central Poland is a promising region where winemaking is developing (Maciejewska et al., 2024). The location of large urban agglomerations in this area

may be a demand factor for developing vineyards focused on enotourism, especially for short, one-day or weekend visits. It was therefore important to check among the respondents whether they knew the enotourism offer in this region, as well as to determine the factors that may influence the use of enotourism services. The third part of the survey was a specification specifying, among others, gender, age, education, place of residence, disposable income of respondents, as well as economic and social situation.

2.2. Statistical Analysis

As part of the preliminary analysis, the distribution and characteristics of the analyzed variables were assessed, divided into the frequency of visiting enotourism places in Poland. The dependent variable of the model was "frequency of visiting enotourism places in Poland". Due to the dichotomous nature of the dependent variable (regressor) "never or once in life", "at least once every few years (several times in life)", a logistic regression model was used. A prediction was made for the level "at least once every few years (several times in life)". Independent variables (regressants) of the model were also determined, including: enotourism places, time spent on such trips, and money spent on such purposes. The developed model included only statistically significant variables. The quality of the obtained model and the accuracy of the prediction were assessed based on Hosmer and Lemeshow Goodness-of-Fit. The C-statistic value and the Hosmer and Lemeshow goodness-of-fit test were used to assess the quality of the resulting model. All analyses were performed using the SAS 9.4 (Field, 2024).

3. Results

The sample consisted of 984 participants (640 women and 344 men) over 18 years old. Respondents were also divided by their education, place of residence, and subregion. Respondents were also asked about disposable income and socioeconomic situation. Table 1 displays the characteristics of the study sample.

Table 1.
Socio-demographic characteristics of the study sample

Variables		Total Sample	
		N	%
Total Sample		984	100.0
Gender	Woman	640	65.0
	Men	344	35.0
Age	18-30	369	37.5
	31-45	333	33.8
	46-60	220	22.4
	Under 60	62	6.3

Cont. table 1.

Education	Primary	37	3.7
	Medium	94	9.6
	Above	853	86.7
Accommodation	Village	196	19.9
	A city with a population of less than 50 thousand	135	13.7
	A city with a population of 50 to 99,9 thousand	200	20.3
	A city with a population of 100 to 250 thousand	304	30.9
	A city with a population of over 250 thousand	149	15.1
Macroregion	Northern	201	20.5
	Northwest	147	15.4
	Southwest	93	9.5
	Southern	108	11
	Central	307	31.2
	Eastern	128	13.1
Monthly income	Up to 60 EUR	97	9.8
	121-180 EUR	245	24.9
	Above 180 EUR	642	65.2
Socio-economic group	Currently not working anywhere	5	0.5
	Student	107	10.9
	Pensioner	122	12.4
	Farmer	122	12.4
	Blue collar worker	56	5.7
	Clerk	123	12.5
	Employee working for a company/office	377	38.3
	Self-employed	182	18.5

Source: Own study.

As already indicated in the introduction, enotourism in Poland is still a developing branch of tourism. The research showed that just over half (50.7%) of all respondents had ever been to a vineyard (regardless of whether in Poland or abroad). Various factors influence the likelihood of visiting wine tourism destinations. People who, based on surveys, visited places related to wine tourism in the past year both in Poland and abroad have a 2.6 times greater chance of visiting such places in Poland at least once a year compared to people who did not visit all such places (OR: 2.60; 95% CI: 1.10-6.14). However, people who visited a wine center abroad in the last year have a 42.9% greater chance of visiting such centers in Poland at least once a year compared to people who did not visit such a place (OR: 1.43; 95% CI: 1.16-1.82). It is interesting that people who spend half a day in places offering wine tourism have an 8.5 times greater chance of visiting such a center in Poland at least once a year compared to people who did not spend time there (OR: 4.48; 95% CI: 1/03-69/93). People staying all day in wine centers have a five times greater chance of visiting such places in Poland at least once a year (OR: 5.05; 95% CI: 1.59-43.07). However, people spending 2-3 days there have an 11.6 times greater chance of visiting such places in Poland at least once a year (OR: 11.65; 95% CI: 1.35-100.72).

Apart from the time spent on enotourism trips, it was decided to examine how the declared financial resources allocated to enotourism trips among respondents may influence the use of the enotourism offer of Polish vineyards. The research has shown that people willing to spend EUR 60-120 on accommodation services during enotourism trips have a 28% greater chance of

going on an enotourism trip in Poland compared to people willing to spend up to EUR 60 per person (OR: 1.28; 95% CI: 1.05-2/08). However, people willing to spend EUR 121-180 have a 32% greater chance of going on an enotourism trip located in Poland (OR: 1.32; 95% CI: 1.06-2.79). However, people willing to spend over EUR 180 have a 162% greater chance of going on an enotourism trip to Poland (OR: 2.62; 95% CI: 1.44-15.69). Moreover, respondents who intend to use additional attractions during an eco-tourism trip have a 45% greater chance of visiting these places more often than people who do not use them (OR: 1.45, 95% CI: 1.09-2.30). People interested in wine and wine regions are almost twice as likely to visit these places more often than people who are not interested (OR: 1.97; 95% CI: 1.15-4.10) (Table 2).

Table 2.

Statistically significant variables and their estimation properties used to build the logistic regression model

Variable		Estimate	Point Estimate	Pr>ChiSq
How many places related to wine tourism have you been to in the past year?		-2.587		0.013
	Poland	-0.033	0.968	0.9315
	Poland and other countries	0.9538	2.596	0.0298
	Other countries	0.3575	1.429	0.0144
	Wasn't	0	1	
How much do you spend time on average in places offering wine tourism?	Half day	2.1381	8.483	0.047
	Whole day	1.6188	5.047	0.0489
	2-3 days	2.4551	11.647	0.0257
	More than 3 days	1.6225	5.066	0.1587
	1,5 week	16.8915	>999.999	0.9842
	Don't spend	0		
How much money on average do you spend per person on an enotourism trip?	Up to 60 EUR	0		
	60 -120 EUR	0.2479	1.281	0.0112
	120-180 EUR	0.276	1.318	0.0471
	Above 180 EUR	0.9623	2.618	0.0292
Enjoyment of additional attractions	Yes	0.3695	1.447	0.0375
	No	0		
Interest in winemaking – wine regions	Yes	0.6797	1.973	0.0487
	No	0		

Source: Own study.

Research has shown that people who are motivated by the desire to learn new things are twice as likely to go on regular tourist trips located in central Poland compared to people for whom this issue is not important. This may mean that novelties related to vineyards, such as new wine varieties, new production techniques, or interesting wine events, are a key factor attracting these tourists. Visitors who were attracted by events organized by vineyard owners have over six times greater chance of regular enotourism trips compared to people for whom these events are not important. These events are a strong motivating factor for people practicing enotourism. The belief that wines from vineyards in central Poland can be of high quality paradoxically limits regular enotourism. Each additional point in this opinion reduces the chance of regular visits to vineyards by 41%. This may be due to the fact that tourists who have already rated the wines as high-quality products may not feel the need to return, believing that

they have already experienced the best products of the region. The research also showed that people who consider central Poland to be a good region for the development of enotourism have a 64% greater chance of being frequent visitors to vineyards at every level of this opinion. This means that a positive perception of the region strongly correlates with greater interest and regular visits by enotourists (Table 3).

Table 3.

Statistically significant variables and their estimation properties were used to build the logistic regression model

Variable		Estimate	Point Estimate	Pr>ChiSq
What prompted you to visit a winery in central Poland? – novelty		0.4572		0.6752
	Yes	0.7138	2.042	0.0185
	No	0		
What prompted you to visit a winery in central Poland? – events organized by the owner of the winery	Yes	1.8106	6.114	0.016
	No	0		
Objectives of visits to vineyards in central Poland – expanding information on wines	Yes	-0.5316	0.588	0.0264
	No	0		
Wines from vineyards located in central Poland can be a high-quality product		-0.6603	0.517	0.0115
Central Poland is a good region to develop enotourism services		0.4971	1.644	0.0455

Source: Own study.

4. Discussion

Enotourism in Poland, although still in the development phase, has great potential. Many studies emphasize the importance of appropriate promotion as a key factor influencing the development of this form of tourism in Poland (Jesiotr, Szymańska, 2016). In central Poland, winemaking and enotourism can become an important element of the local economy if they are properly developed and promoted. Research conducted by Sidorkiewicz (2023) shows that Poland as an enotourism destination has a lot to offer. The Polish enotourism product model includes natural values, local and regional enotourism products, as well as units supporting and promoting enotourism. Nevertheless, the development of enotourism in central Poland encounters many challenges, such as the need for changes in legal regulations regarding winemaking and the need for cooperation between local authorities and the tourism industry. Consumers of enotourism are interested not only in wine tasting, but also in the opportunity to spend time outdoors, visiting nearby tourist attractions and participating in local cultural events (Roman, Prus, 2020). Survey research conducted in central Poland shows that there is significant potential for the development of enotourism if these expectations are properly taken into account in the tourist offer. It should be emphasized, however, that this development will depend on the further development of vineyards and the increase in grape cultivation in this region. Examples from other regions, such as the Pod-Carpathian Voivodeship, show that

enotourism can be an effective tool for activating rural areas (Kuźniar, 2012). Wine tourism can also make a significant contribution to the economic development of rural regions, increasing the income of local wine producers and creating new jobs. In Chile, the development of enotourism has contributed to the diversification of the economy, which was previously heavily dependent on extractive sectors (Fuguerora, Rotarou, 2018). It also supports social development by preserving and promoting local cultural heritage. This is particularly evident in regions such as Somontano in Spain, where wineries create emotional experiential bonds with tourists, which promotes social sustainability (Cristòfol et al., 2020). Sustainable development of enotourism also includes care for the natural environment. In Spain, the sustainable development of enotourism is based on respect for local natural resources and landscape, which is crucial for the long-term success of this form of tourism (De La Torre et al., 2008). A similar approach can be seen in Poland, where regions like the Podkarpackie Voivodeship have emphasised the importance of integrating enotourism with local natural and cultural heritage. This region, known for its scenic landscapes and traditional agricultural practices, has successfully combined wine production with tourism to enhance both economic viability and cultural preservation (Kuźniar, 2012). Moreover, the Lubuskie Voivodeship has developed its enotourism sector by focusing on the natural beauty of the region and its historical ties to viticulture. This area demonstrates how respect for natural resources and the landscape can create a sustainable tourism model that not only attracts visitors but also supports local wine producers (Greinert et al., 2019). Examples from other regions, such as the Małopolska Voivodeship, also illustrate the potential for tourism to become a vital part of the local economy. This region, with its rich cultural heritage and growing number of vineyards, shows how enotourism can be integrated with other forms of tourism to create a diversified and sustainable economic base (Bajgier-Kowalska et al., 2017).

5. Conclusions

Enotourism is a form of tourism that connects wine lovers with visits to vineyards, tastings and learning about wine production processes. Traditionally associated with regions such as France, Italy and Spain, it is also starting to gain popularity in less known wine regions. Central Poland, despite the lack of wine traditions comparable to the above-mentioned countries, has a chance to join this trend, especially in the context of global climate change, which affects shifts in wine-growing zones. Thanks to its central location and various natural and cultural values, it has favorable conditions for the development of enotourism. Research clearly shows that various factors such as: previous experience with enotourism, time spent in wine resorts, accommodation expenses, use of additional attractions, interest in winemaking, news and events organized by vineyards are the key factors attracting enotourists

to Poland central. At the same time, the positive perception of the region as a good place for the development of enotourism strongly correlates with the frequency of tourists' visits to vineyards. To maintain the interest of enotourists, wineries should constantly introduce innovations and organize various events that will attract both new and returning guests. This requires cooperation between wine producers, local authorities and tourist organizations. It is also crucial to invest in tourist infrastructure, education and promotion of the region as an enotourism destination. Examples of successful enotourism development strategies from other regions of the world can be an inspiration for winemakers from central Poland. It is also important to understand the expectations of consumers, who are increasingly looking for authentic, ecological and educational tourism experiences. The development of enotourism in central Poland is a real possibility, which, however, requires an organized approach and cooperation of various entities. Available literature suggests that running a vineyard may not always ensure full profitability, but adding enotourism activities significantly increases the chances of achieving stable income. These activities can include not only direct product sales but also the organization of events that strengthen the bond between customers, the wine brand, and the region where it is produced. Integrating enotourism with agricultural production offers real opportunities to increase farm income while contributing to greater financial stability and the development of local communities. In the face of growing challenges in agriculture, such an approach represents a modern and effective strategy for the future.

The conducted analyses, while providing valuable insights that lays the groundwork for further research. However, such comparison will require additional studies to be conducted in subsequent years to observe trends and changes over time. It is essential to emphasize that the main limitation of this study lies in its one-time nature capturing a snapshot from 2024. This limits the ability to assess longitudinal trends or predict future developments in enotourism preferences and influencing factors, such as climate representative understanding of enotourism in Poland. Future studies should aim to focus on regional specificities by including comparative analyses across voivodeships. This approach would help to uncover localized factors and differences influenced by Poland's diverse socio-cultural and environmental characteristics. Moreover, studies focusing on the impact of infrastructure development – such as transport, accommodation and additional attractions – on the region's enotourism appeal would offer actionable insights. Comparative analyses between central Poland and other regions with similar climatic and viticultural conditions could highlight best practices. The role of sustainable and eco-friendly practices in attracting modern enotourists should also be explored, alongside the influence of climate changes on vineyard suitability. Furthermore, assessing the economic and social benefits of enotourism for local communities, including job creation and income generation would underline its broader impact. Exploring the use of emerging technologies like mobile applications or virtual reality to enhance the tourists experience and promote the region would provide valuable direction for innovation. This study demonstrates the significant value of building upon its foundations to explore enotourism's potential comprehensively and sustainably.

References

1. Alonso, A.D., Liu, Y. (2020). Visitor Centers, Collaboration and the Role of Local Food and Beverage as Regional Tourism Development Tools: The Case of the Blackwood River Valley in Western Australia. *J. Hosp. Tour Res*, Vol. 35, Iss. 4, pp. 517-536, doi: <http://dx.doi.org/10.1177/1096348011413594>
2. Anastasiadis, F., Alebaki, M. (2021). Mapping the Greek wine supply chain: A proposed framework. *Foods*, Vol. 10, Iss. 11, No. 2859, doi: <https://doi.org/10.3390/foods10112859>
3. Baird, T., Hall, M., Castka, P. (2018). New Zealand Winegrowers Attitudes and Behaviours towards Wine Tourism and Sustainable Winegrowing. *Sustainability*, Vol. 10, Iss. 3, pp. 797, doi: <https://doi.org/10.3390/su10030797>
4. Bajgier-Kowalska, M., Tracz, M., Uliszak, R. (2017). Modeling the state of agritourism in the Malopolska region of Poland. *Tourism Geographies*, Vol. 3, pp. 502-524, doi: <https://doi.org/10.1080/14616688.2017.1300935>.
5. Baker, L.R. (2016). *Behavior Intentions of Wine Tourists in Southern New Jersey Using the Experience Economy Framework* (Doctoral dissertation). Delaware: Wilmington University, 29.
6. Bibiciou, S., Cretu, R.C. (2013). Enoturism: A niche tendency within the turism market. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rual Development*, Vol. 13, pp. 31-40.
7. Bosak, W. (2013). Opłacalność produkcji wina oraz możliwości rozwoju komercyjnego winiarstwa w Polsce. *Polski Instytut Wina i Winorośli*, pp. 1-24.
8. Bruwer, J. (2003). South African wine routes: Some perspectives on the wine tourism industry's structural dimensions and wine tourism product. *Toursim Manage*, Vol. 24, Iss. 4, pp. 423-435, doi: [http://dx.doi.org/10.1016/S0261-5177\(02\)00105-X](http://dx.doi.org/10.1016/S0261-5177(02)00105-X)
9. Brzózka, B., Jaczewski, A. (2016). Potential effect of future climate changes on productivity of selected crops in Poland. *Ananal of Warsaw University of Life Sciences*, Vol. 48, Iss. 2, pp. 173-184, doi: <http://dx.doi.org/10.1515/ssggw-2016-0014>
10. Bunghez, C.L. (2022). Enoturism: Analysis and Case Study *Journal of Eastern Europe. Research in Business & Economics*, pp. 1-8.
11. Byrd, E.T., Canziani, B., Hsieh, Y.C., Debbage, K. (2015). Wine tourism: Motivating visitors through core and supplementary services. *Tour. Manag*, Vol. 52, pp. 19-29, doi: <http://dx.doi.org/10.1016/j.tourman.2015.06.009>
12. Carlsen, J., Boksberger, P. (2015). Enhancing consumer value in wine tourism. *J. Hosp. Tour Res*, Vol. 39, pp. 132-144.
13. Carlsen, J., Dowling, R. (1998). Wine Tourism Marketing Issues in Australia. *Int. J. Wine Mark*, Vol. 10, pp. 23-32.

14. Charters, S., Ali-Knight, J. (2002). Who is the wine tourist? *Tour. Manag*, Vol. 23, Iss. 3, pp. 311-319, doi: [http://dx.doi.org/10.1016/S0261-5177\(01\)00079-6](http://dx.doi.org/10.1016/S0261-5177(01)00079-6)
15. Charters, S., Fountain, J., Fish, N. (2009). You felt like lingering... Experiencing “real” service at the winery tasting room. *Journal of Travel Research*, Vol. 48, Iss. 1, pp. 122-143, doi: <https://doi.org/10.1177/0047287508326508>
16. Cristòfol, F., Zamarreño Aramendia, G., de-San-Eugenio-Vela, J. (2020). Effects of Social Media on Enotourism. Two Cases Study: Okanagan Valley (Canada) and Somontano (Spain). *Sustainability*, Vol. 12, Iss. 17, No. 6705, doi: <https://doi.org/10.3390/su12176705>
17. De La Torre, G.M.V., Navarro, A.M., Guzman, T.J.L.G. (2008). Denominação de origem Alicante (Espanha): um estudo preliminar para a implantação do enoturismo. *Turismo: Visão e Ação*, Vol. 10, pp. 7-22.
18. Dec, B., Krupa, J. (2014). *Możliwości wzbogacenia oferty turystycznej w obszarze turystyki winiarskiej na Podkarpaciu*. Dyniów, Poland: Związek Gmin Turystycznych Pogórza Dynowskiego, pp. 151-162.
19. Dodd, T.H., Gustafon, A.W. (1997). Product, environmental, and service attributes that influence consumer attitudes and purchases at wineries. *Journal of Food Products Marketing*, Vol. 4, pp. 41-59, doi: http://dx.doi.org/10.1300/J038v04n03_04
20. Dominik, P. (2016). Edukacyjna rola szlaków kulinarnych. *Przedsiębiorczość – Edukacja*, Vol. 12, No. 284, doi: <https://doi.org/10.24917/20833296.12.21>
21. Dreyer, A. (2019). *Wine Plus Tourism Offers: It is Not All about Wine-Wine Tourism in Germany*. Wine Tourism Destination Management and Marketing-Theory and Cases. London, UK: Palgrave Macmillian Cham, pp. 399-421.
22. Droulia, F., Charalampopoulos, I. (2021). Future Climate Change Impacts on European Viticulture: A Review on Recent Scientific Advances. *Atmosphere*, Vol. 12, Iss. 4, No. 495, doi: <https://doi.org/10.3390/atmos12040495>
23. Field, A. (2024). *Discovering Statistics Using IBM SPSS Statistics*. New York, USA: SAGE Publications Limited.
24. Figueroa, B.E., Rotarou, E. (2018). Challenges and opportunities for the sustainable development of the wine tourism sector in Chile. *Journal of Wine Research*, Vol. 29, Iss. 1, pp. 243-264, doi: <https://doi.org/10.1080/09571264.2018.1532880>.
25. Founatin, J. (2014). *Who's there? An exploratory study of the characteristic and wine consumption behaviours of visitors at a New Zeland wine festival*. Proceeding of the 8th Academy of Wine Business Research Conference. Geisenheim, Germany, pp. 28-30.
26. Fraga, H., Malheiro, A.C., Mouthio-Pereire, J., Santos, J.A. (2013). Future scenarios for viticultural zoning in Europe: ensemble projections and uncertainties. *International Journal of Biometeorology*, Vol. 57, Iss. 6, pp. 909-925, doi: <http://dx.doi.org/10.1007/s00484-012-0617-8>
27. Fuentez-Fernandez, R., Martinez-Falco, J., Sanchez-Garcia, J., Sanchez-Garcia, E., Marco-Lajara, B. (2022). Does Ecological Agriculture Moderate the Relationship between Wine

- Tourism and Economic Performance? A Structural Equation Analysis Applied to the Ribera del Duero Wine Context. *Agriculture*, Vol. 12, Iss. 2, No. 2, doi: <https://doi.org/10.3390/agriculture12122143>
28. Getz, D., Brown, G. (2006). Benchmarking wine tourism development; The case of the Okanagan Valley, British Columbia, Canada. *Int. J. Wine Mark*, Vol. 18, Iss. 2, pp. 78-97, doi: <http://dx.doi.org/10.1108/09547540610681077>
29. Getz, D., Brown, G. (2006). Critical success factors for wine tourism regions: a demand analysis. *Tourism Management*, Vol. 27, Iss. 1, pp. 146-158, doi: <https://doi.org/10.1016/j.tourman.2004.08.002>
30. Gomez, M., Pratt, M.A., Molina, A. (2019). Wine tourism research: a systematic review of 20 vintages from 1995 to 2014. *Current Issues in Tourism*, Vol. 22, pp. 2211-2259, doi: <http://dx.doi.org/10.1080/13683500.2018.1441267>
31. Grabowski, T. (2018). Programy edukacyjne w polskich winnicach. *Wine Tourism Review*, Vol. 9, pp. 22-29.
32. Greinert, A., Kostecki, J., Vystavna, Y. (2019). The history of viticultural land use as a determinant of contemporary regional development in Western Poland. *Land Use Policy*, Vol. 85, pp. 249-258, doi: <https://doi.org/10.1016/J.LANDUSEPOL.2019.04.010>.
33. Hall, C., Mitchell, R. (2000). Wine Tourism in the Mediterranean: A Tool for Restructuring and Development. *Thunderbird In. Bus. Rev*, Vol. 42, pp. 445-465, doi: [http://dx.doi.org/10.1002/1520-6874\(200007/08\)42:43.O.CO;2-H](http://dx.doi.org/10.1002/1520-6874(200007/08)42:43.O.CO;2-H)
34. Hall, C.M., Gossling, S. (2016). *From food tourism and regional development to food, tourism and regional development: Themes and issues in contemporary foodscapes. Food Tourism and Regional Development Networks, Products and Trajectories*. Abingdon, UK: Routledge, pp. 23-57.
35. Hall, C.M., Macions, N. (1998). Wine Tourism in Australia and New Zealand. *Tourism and Recreation in Rural Areas*, pp. 267-298.
36. Hall, C.M., Sharples, L., Cambourne, B., Macionis, N. (2000). *Wine Tourism around the World*. Oxford, UK: Butterworth-Heinemann.
37. Hannah, L., Roehrdanz, P., Ikegami, M., Shepard, A., Shaw, M., Tabor, G., Zhi, L., Marquet, P., Hijmans, R. (2013). Climate change, wine, and conservation. *Proceedings of the National Academy of Sciences*, Vol. 110, Iss. 17, pp. 6907-6912, doi: <https://doi.org/10.1073/pnas.1210127110>
38. Jaykumar, V., Fukey, L. (2014). Issues and Opportunities of Niche Tourism Markets- Understanding South India Wine Tourism. *Developing Country Studies*, Vol. 4, Iss. 6, pp. 51-59.
39. Jesiotr, K., Szymańska, E. (2016). Enotourism: A New Profitable Business? Poland's Case. *Business Challenges in the Changing Economic Landscape*, Vol. 1, pp. 411-421, doi: https://doi.org/10.1007/978-3-319-22596-8_29.

40. Jeziorska-Biel, P., Leśniewska-Napierała, K., Czpilewski, K. (2021). (Circular) Path Dependence-The Role of Vineyards in Land Use, Society and Regional Development - The Case of Lubuskie Region (Poland). *Energies*, Vol. 14, Iss. 24, doi: <https://doi.org/10.3390/en14248425>
41. Johnson, H., Robinson, J. (2019). *Atlas świata wina; Explanator after hours*. Poznań, Poland.
42. Kolek, M. (2023). Winnice jako niewykorzystany walor rozwoju enoturystyki w wybranych miastach Polski. *Studia Miejskie*, Vol. 45, pp. 75-91.
43. Kołodziej, I.A. (2022). Specyfika i perspektywy rozwoju enoturystyki w województwie dolnośląskim. *Turystyka i Rozwój Regionalny*, pp. 89-98, doi: <https://doi.org/10.22630/TIRR.2022.18.21>
44. Kosmaczewska, J. (2006). Turystyka z winem w tle. Czy polska ma szanse zaistnieć na rynku enoturystyki? *Folia Turistica*, Vol. 17, pp. 153-162.
45. Kowalczyk, A. (2010). *Turystyka winiarska. Turystyka zrównowazona*. Warszawa, Poland: PWN, pp. 208-230.
46. Kowalski, P. (2021). Zielone praktyki w polskich winnicach. *Wine & Vine*, Vol. 12, pp. 35-47
47. KOWR (2024). *Krajowy Ośrodek Wsparcia Rolnictwa. Ewidencja winnic stan na 29.08.2024 r.* Retrieved from: <https://www.gov.pl/web/kowr/wykazy--rejstry>, 1.09.2024.
48. Koźmiński, C., Mąkosza, A., Michalska, B., Nidzgorska-Lencewicz, J. (2020). Thermal Conditions for Viticulture in Poland. *Sustainability*, Vol. 12, Iss. 14, doi: <https://doi.org/10.3390/su12145665>
49. Krupa, J., Stokłosa, Ł. (2015). Winnice oraz imprezy winiarskie atrakcją turystyczną regionu. *Europa Regionu*, Vol. 23, pp. 258-270.
50. Kundzewicz, W.Z., Pniewski, M., Mezghani, A., Okruszko, T., Pińskawar, I., Kardel, I., Hov, O., Szcześniak, M., Szwed, M., Benestad, R., Marcinkowski, P., Graczyk, D., Dobler, A., Forland, E.J., O'Keete, J., Choryński, A., Parding, K.M., Haugen, J.E. (2018). Assesment of climate change and associated impact on selected sectors in Poland. *Acta Geophysica*, Vol. 66, pp. 1509-1523, doi: <https://doi.org/10.1007/s11600-018-0220-4>
51. Kunicka-Styczyńska, A., Czyżowska, A., Ratajkowska, K., Witkowska, A., Dziugan, P. (2016). The trends and prospects of winemaking in Poland. *Grape and Wine Biotechnology*, pp. 401-413, doi: 10.5772/64976
52. Kuźniar, W. (2012). Wybrane aspekty rozwoju produktów markowych w turystyce wiejskiej. *Marketing i Zarządzanie*, Vol. 23, pp. 173-185.
53. Lewandowski, K. (2023). Wykorzystanie energii odnawialnej w winnicach. *Green Energy Journal*, Vol. 13, pp. 38-52, doi: <https://doi.org/10.15611/pn.2016.453.15>
54. Lopez-Guzman, T., Veira-Rodriguez, A., Rodriguez-Garcia, J. (2014). Profile and motivations of European tourists on the Sherry wine route of Spain. *Tour Manag. Persp*, Vol. 11, pp. 63-68, doi: <http://dx.doi.org/10.1016/j.tmp.2014.04.003>

55. Luo, Y., Xiong, T., Meng, D., Gao, A., Chen, Y. (2023). Does the Integrated Development of Agriculture and Tourism Promote Farmers' Income Growth? Evidence from Southwestern China. *Agriculture*, Vol. 13, Iss. 9, doi: <https://doi.org/10.3390/agriculture13091817>.
56. Maciejczak, M., Mikciuk, J. (2018). Climate change impact on viticulture in Poland. *International Journal of Climate Change Strategies and Management*, Vol. 11, Iss. 2, pp. 254-264, doi: <http://dx.doi.org/10.1108/IJCCSM-02-2018-0021>
57. Maciejewska, D., Olewnicki, D., Stangierska-Mazurkiewicz, D., Tyminski, M., Latocha, P. (2024). Impact of Climate Change on the Development of Viticulture in Central Poland: Autoregression Modeling SAT Indicator. *Agriculture*, Vol. 144, Iss. 6, doi: <https://doi.org/10.3390/agriculture14050748>
58. Majewski, R. (2022). Wpływ zrównoważonej turystyki winiarskiej na lokalne społeczności. *Regional Development Quarterly*, Vol. 14, pp. 77-92.
59. Marcinkowski, P., Pniewski, M. (2018). Effect of climate change on sowing and harvest dates of spring barley and maize in Poland. *International Agrophysics*, Vol. 32, pp. 265-271, doi: <https://doi.org/10.1515/intag-2017-0015>
60. Mariani, G., Rossi, F., Bianchi, L. (2022). Wine tourism and sustainable practices. *Journal of Sustainable Tourism*, Vol. 30, pp. 123-145.
61. McNamara, N., Cassady, F. (2015). Wine tasting: To charge or not to charge? *Int. J. Hosp. Manag.*, Vol. 49, pp. 8-16, doi: <http://dx.doi.org/10.1016/j.ijhm.2015.05.004>
62. Mitchell, R., Charters, S., Albrecht, J.N. (2012). Cultural systems and the wine tourism products. *Annals of Tourism Research*, Vol. 39, pp. 311-355, doi: 10.1016/j.annals.2011.05.002
63. Myga-Piątek, U., Rahmonov, O. (2018). Winery regions as the oldest cultural landscapes: remnants, signs, and metamorphoses. *Miscellanea Geographica*, Vol. 22, Iss. 2, pp. 69-80, doi: <https://doi.org/10.2478/mgrsd-2018-0009>
64. Myśliwiec, R. (1992). *Uprawa winorośli*. Warszawa, Poland: Państwowe Wydawnictwo Rolnicze i Leśne.
65. Nella, A., Christou, E. (2021). Market segmentation for wine tourism: Identifying sub-groups of winery visitors. *European Journal of Tourism Research*, Vol. 29, p. 2903, doi: <https://doi.org/10.54055/ejtr.v29i.2414>
66. Nowak, J. (2022). Ekologiczne metody uprawy winorośli w Polsce. *Journal of Sustainable Agriculture*, Vol. 15, pp. 45-60.
67. Olaru, O. (2012). Wine tourism – An opportunity for the development of wine industry. *An. Ser. Stiinte Econ. Timis*, Vol. 18, pp. 158-165.
68. Olewnicki, D. (2018). Uprawa winorośli w Polsce w świetle danych statystycznych. *Roczniki Naukowe Stowarzyszenia Ekonomistów Rolnictwa i Agrobiznesu*, Vol. 5, pp. 139-145.

69. Olszewski, J., Drózd, R. (2013). Polska oferta w zakresie „Enoturystyki”. *Hygeia Public Health*, Vol. 48, Iss. 4, pp. 436-440.
70. Polska Organizacja Turystyczna (2014). *Enoturystyka w Polsce - poznaj piękno naszych winnic*. Retrieved from: <https://www.polska.travel/enoturystyka-w-polsce-poznaj-piekno-naszych-winnic/>, 1.09.2024.
71. Pomarici, E., Vecchio, R. (2017). Consumer preferences for sustainable wine. *Journal of Wine Economics*, Vol. 12, pp. 345-368.
72. Pratt, M., Molina, A. (2019). Economic impacts of wine tourism. *Journal of Wine Economics*, Vol. 14, pp. 250-267.
73. Pulpon, A., Ruiz, C. (2019). Potential of vineyard landscapes for sustainable tourism. *Geosciences*, Vol. 9, Iss. 11, doi: <https://doi.org/10.3390/geosciences9110472>
74. Remenova, K., Skorkova, Z., Jankelova, N. (2019). Wine tourism as an increasingly valuable revenue stream of a winery's business model. *Ekonom. Poljopr.*, Vol. 66, Iss. 1, pp. 23-43, doi: <http://dx.doi.org/10.5937/ekoPolj1901023R>
75. Ribero Santos, V., Ramos, P., Almeida, N., Santos-Pavon, E. (2019). Wine and wine tourism experience: a theoretical and conceptual review. *Worldwide Hospitality and Tourism Themes*, Vol. 11, Iss. 6, pp. 718-730, doi: <https://doi.org/10.1108/WHATT-09-2019-0053>
76. Roman, M., Roman, M., Prus, P. (2020). Innovations in Agritourism: Evidence from a Region in Poland. *Sustainability*, Vol. 12, Iss. 12, doi: <https://doi.org/10.3390/su12124858>
77. Romanowicz, R., Bogdanowicz, E., Debele, S.E., Doroszkiewicz, J., Hisdal, H., Lawrence, D., Meresa, H.K., Napiórkowski, J., Osuch, M., Strupczewski, W.G., Wilson, D., Wong, W.K. (2016). Climate Change Impact on Hydrological Extremes: Preliminary Results from the Polish-Norwegian Project. *Acta Geophysica*, Vol. 64, pp. 477-509.
78. Santos, J.A., Fraga, H., Malheiro, A., Moutinho-Pereira, J., Dinis, L., Correria, C., Moriondo, M., Leolini, L., Dibari, C., Costafreda-Aumendes, S., Kartschall, T., Menz, C., Molitor, D., Junk, J., Beyer, M., Dchultz, H.R. (2020). A Review of the Potential Climate Change Impacts and Adaptation Options for European Viticulture. *Applied Sciences*, Vol. 10, doi: <https://doi.org/10.3390/app10093092>
79. Schernewski, G. (2011). Adaptation to climate change: viniculture and tourism at the Baltic coast. Global change and Baltic coastal zones. *Springer*, Vol. 1, pp. 249-273.
80. Seo, S. (2010). Is an integrated farm more resilient against climate change? A micro-econometric analysis of portfolio diversification in African agriculture. *Food Policy*, Vol. 35, Iss. 1, pp. 32-40, doi: <https://doi.org/10.1016/J.FOODPOL.2009.06.004>.
81. Serra, M., Antonio, N., Henriques, C., Alfonso, C.M. (2021). Promoting Sustainability through Regional Food and Wine Pairing. *Sustainability*, Vol. 13, Iss. 24, doi: <https://doi.org/10.3390/su132413759>
82. Sidorkiewicz, M. (2023). Analysis of Poland's Enotourism Product Model. *Quaestiones Geographicae*, Vol. 42, pp. 107-199, doi: <https://doi.org/10.14746/quageo-2023-0033>.

83. Singh, Y., Drakeman, D. (2020). Measuring the carbon foodprint of wine tourism and cellar door sales. *Journal of Cleaner Production*, Vol. 266, doi: <http://dx.doi.org/10.1016/j.jclepro.2020.121937>
84. Smogór, J. (2012). Wpływ autostrady Warszawa–Berlin na rozwój enoturystyki w województwie lubuskim. *Zeszyty Naukowe Wielkopolskiej Wyższej Szkoły Turystyki i Zarządzania w Poznaniu*, Vol. 7, pp. 121-130.
85. Smyczek, S., Festa, G., Rossi, M., Monge, F. (2020). Economic sustainability of wine tourism services and direct sales performance – emergent profiles from Italy. *Brit. Food. J.*, Vol. 122, pp. 1519-1529.
86. Sokół, J.L. (2015). Perspektywy rozwoju turystyki winiarskiej w Polsce – szanse i bariery. *Zeszyty Naukowe Turystyka i Rekreacja*, Vol. 2, pp. 39-48.
87. Sottini, V.A., Barbierato, E., Bernetti, I., Capecchi, I. (2021). Impact of Climate Change on Wine Tourism: An Approach through Social Media Data. *Sustainability*, Vol. 13, Iss. 13, doi: <https://doi.org/10.3390/su13137489>
88. Szumelda, A. (2019). Agriculture and everyday realities on small farms – An entrepreneurial challenge to farmers between the desire for autonomy and a secure existence. *Journal of Rural Studies*, Vol. 67, pp. 57-68, doi: <https://doi.org/10.1016/j.jrurstud.2019.02.008>
89. Szwed, M., Karg, G., Pińskwar, I., Radziejewski, M., Graczyk, D., Kędziora, A., Kundzewicz, Z.W. (2010). Climate change its effect on agriculture, water resources and human health sectors in Poland. *Natural Hazards and Earth System Sciences*, Vol. 10, Iss. 8, pp. 1725-1737, doi: <https://doi.org/10.5194/nhess-10-1725-2010>
90. Szymańska, E. (2012). Zarządzanie zasobami wodnymi w produkcji wina. *Environmental Practices in Viticulture*, Vol. 10, pp. 40-55.
91. Tafel, M.C., Szolonki, G. (2021). Relevance and challenges of wine tourism in Germany: A winery operators' perspective. *In. J. Wine. Bus.*, Vol. 33, pp. 60-79.
92. Telfer, D.J. (2001). Strategic alliances along the Niagara Wine Route. *Tour Manag.*, Vol. 22, pp. 21-30.
93. Telfer, S.J. (2001). From wine tourism village to regional wine route: an investigation of the competitive advantage of embedded clusters in Niagara, Canada. *Tourism Recreation Research*, Vol. 25, Iss. 6, pp. 23-33, doi: <http://dx.doi.org/10.1080/02508281.2001.11081340>
94. Thanh, T.V., Kirova, V. (2018). Wine tourism experience: A netnography study. *Journal of Business Research*, Vol. 83, pp. 30-37, doi: <https://doi.org/10.1016/j.jbusres.2017.10.008>
95. Trestini, S., Stiletto, A., Stranieri, S. (2020). Price Determinants of Sparkling Wine in Poland: Does Reputation Really Matter? *Wine Economics and Policy*, Vol. 9, Iss. 1, pp. 73-84, doi: <https://doi.org/10.36253/web-8018>.

96. Trigo, A., Silva, P. (2022). Sustainable Development Directions for Wine Tourism in Douro Wine Region, Portugal. *Sustainability*, Vol. 14, Iss. 7, doi: <https://doi.org/10.3390/su14073949>
97. Vazquez Vincente, G., Barroso, M., Jimenez, B. (2021). Sustainable tourism, economic growth and employment – the case of the wine routes of Spain. *Sustainability*, Vol. 13, Iss. 3, doi: <https://doi.org/10.3390/su13137164>
98. Vinci, G., Prencipe, S., Abbafati, A., Filippi, M. (2022). Environmental Impact Assessment of an Organic Wine Production in Central Italy: Case Study from Lazio. *Sustainability*, Vol. 14, Iss. 22, pp. 1-16, doi: <https://doi.org/10.3390/su142215483>
99. Weaver, D., Lawton, L. (2002). *Tourism Mangement*. Australia: Wiley, p. 142.
100. Wiśniewski, M. (2020). Edukacja ekologiczna w winnicach. *EcoTourism Today*, Vol. 8, pp. 25-33.
101. Wójcik, A. (2022). Przemiany rynku wina w Polsce. *Krakowie Studia Małopolskie*, Vol. 3, Iss. 25, pp. 149-174.
102. World Tourism Organization (2016). Georgia declaration on wine tourism. *Fostering sustainable tourism development through intangible cultural heritage*, Vol. 25. Madrid, Spain, pp. 1-3.
103. Wrzochalska, A. (2001). *Możliwość alternatywnych kierunków produkcji w gospodarstwach rolnych*. Warszawa, Poland: IERiGŻ.
104. Yadav, M.K., Dixit, S.K. (2022). *The growth and evolution of global wine tourism*. London: Routledge Handbook of Wine Tourism, pp. 15-28.
105. Ye, B., Zhang, H., Yuan, J. (2014). Intentions to participate in wine tourism in an emerging market: Theorization and implications. *J. Hosp. Tour. Res.*, Vol. 42, pp. 1007-1031.
106. Yuan, J., Cai, L.A., Morrison, A.M., Linton, S. (2005). An analysis of wine festival attendees' motivations: A synergy of wine, travel and special events? *J. Vac. Mrk.*, Vol. 11, pp. 37-54.
107. Zainurin, F., Neil, L., Schanzle, H. (2022). Considerations of luxury wine tourism experiences in the new world: three Waiheke Island vinteners. *Journal of Revenue and Pricing Management*, Vol. 21, pp. 344-353.
108. Zealand (2014). *Tourism New Zealand. Tourist Special Interest. Wine Tourism*. New Zealand, Auckland: Tourism Profile.
109. Zielińska, A. (2019). Turystyka winiarska jako narzędzie edukacji ekologicznej. *Tourism & Environment*, Vol. 11, pp. 50-56.

MOQ MODELS REVIEW IN PERSPECTIVE OF 7 WASTES

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Purpose: Paper aims to review available knowledge base about MOQ models and review their application to 7 wastes.

Design/methodology/approach: Research areas were identified through author-assigned keywords linked to individual scientific publications. The multi-stage research process incorporated two bibliometric methods: a systematic literature review and a traditional literature review. Scope of the paper gathers published optimization models of MOQ. Available database was reviewed with the purpose of Collected models are reviewed under the objective of 7 wastes.

Findings: The research identified five models focused on optimizing Minimum Order Quantity (MOQ). Each model addresses inventory-related waste, recognizing inventory costs as a significant factor in overall production expenses. Notably, one model also incorporates transportation and defect costs, providing a broader approach to waste reduction. The data shows a clear trend: as manufacturing costs rise, driven by factors such as inflation and supply chain disruptions, there is an increasing demand for advanced optimization models to mitigate these pressures. These models aim not only to reduce inventory costs but also to enhance production efficiency and quality, supporting manufacturers' ability to remain competitive in a challenging market environment.

Originality/value: Compared to other bibliometric analyses, this study distinguishes itself through the precise syntax of its constructed query. Furthermore, the paper investigates the application of models concerning waste categories recognized in lean management techniques. By identifying forms of waste that have been overlooked in prior research, this study offers valuable insights for researchers and practitioners in determining future research directions.

Keywords: MOQ, optimization, supply chain, lean manufacturing, lean management, 7 waste.

Category of the paper: Literature review.

1. Introduction

Supply chain (SC) is a network of organizations, resources, people, activities and technology involved in the creation and distribution of a product, from the sourcing of raw materials to the delivery to end consumers. It consists of components like suppliers, manufacturers, warehouses, distribution centers, retailers and customers. All of those stakeholders shape processes of procurement, production, logistics, inventory management and order fulfillment (Chopra, Meindl, 2016). Efficiency of the supply chain can be measured by various key performance indicators. Few of the most common ones are businesses waste results, dispatch rate, forecast accuracy and inventory turnover.

Optimizations in supply chain occur on multiple levels under various processes. The ideal and effective supply chain has the ability to balance costs, quality and speed in delivering the goods to the customers fulfilling their demand. Throughout multiple processes during the production, imbalances can lead to increase in costs. In order to improve the efficiency of the company manufacturers aim to identify and minimize such imbalances using various techniques.

Manufacturing, regardless of production volume, is inherently linked to waste. Taiichi Ohno, within the framework of the Toyota Production System, identified and categorized these inefficiencies as the '7 Wastes'. Based on those wastes each supply chain process can be analyzed and right bottle necks can be optimized. The idea is that reducing waste leads to higher quality, lower costs and improved delivery times. Optimization efforts are frequently supported by mathematical models tailored to address specific aspects of supply chain operations or provide a comprehensive, system-wide analysis. The purpose of this study is to evaluate the current body of knowledge on optimization models related to MOQ and to determine which categories of waste these models address.

2. Theoretical foundations of the concept of MOQ models and 7 wastes

Minimum Order Quantity (MOQ) optimization is a critical component of effective supply chain management. This optimization focuses on determining the optimal production or order volume that minimizes operational costs while maintaining an acceptable dispatch rate to customers. The MOQ represents the minimum quantity that a buyer must order from a supplier in a single transaction. Effective management of MOQ seeks to balance ordering costs, inventory levels, and potential business losses.

The significance of MOQ management is particularly pronounced for companies dealing in low-margin products, as high inventory levels can lead to substantial financial losses. By optimizing MOQ, businesses can reduce costs associated with inventory, minimize the risk of obsolescence, and enhance operational efficiency. A key challenge in MOQ optimization lies in accounting for demand variability and lead time uncertainty. These factors necessitate the use of advanced analytical methods, including stochastic modeling and computer simulations, to develop effective strategies (Shenoy, Zhao, 2019; Klamerek, Kutnik, 2023).

In the realm of global supply chains, the complexities associated with MOQ optimization increase significantly due to the diversity of suppliers, variations in delivery times, and fluctuations in transportation costs. In such contexts, well-designed optimization algorithms can lead to significant reductions in operational costs and improved cash flow. Furthermore, effective MOQ management can foster sustainable growth by addressing issues of overproduction and reducing the carbon footprint associated with transportation and inventory.

Research regarding supply chain optimization often integrates MOQ optimization with other operational decisions, such as inventory management, production planning, and transportation logistics. Consequently, MOQ optimization becomes an integral part of comprehensive operations management strategies aimed at enhancing a firm's competitiveness in the marketplace. The process of MOQ optimization is multifaceted, requiring a deep understanding of demand dynamics, cost structures, and operational constraints, positioning it as a vital element of contemporary supply chain management (Gupta et al., 2019; Li et al., 2020; Liu, Zhang, 2021).

Optimization processes are closely related to Lean Management as both aim to maximize efficiency and minimize waste. Lean Management's core objective is to identify and eliminate waste in all forms (e.g. time, materials, any non-value adding efforts). Optimization processes are often used within Lean Management to assess workflows, identify inefficiencies, and find ways to streamline operations, effectively reducing or eliminating these wastes. Lean Management tools encompass various methods and techniques utilized in the management and optimization of both production and service processes. The Lean concept originated in the 1950s at Toyota Motor Corporation in Japan, specifically within the framework of the Toyota Production System (TPS). Since then, it has gained global popularity. Lean Management emerged from post-war Japan, where Kiichiro Toyoda and Taiichi Ohno, inspired by American manufacturing methods such as the Ford Production System, developed their own approach to managing production processes. Initially implemented in Toyota's facilities, this system aimed to improve production efficiency by eliminating all forms of waste (Japanese: muda), defined as activities that do not add value to a product or service from the customer's perspective.

The principles of Lean Management have been widely adopted across various industries, driving significant improvements in operational efficiency and customer satisfaction. Researchers have explored the application of Lean Management in diverse contexts, illustrating their effectiveness in streamlining processes and fostering continuous improvement. One such

application involves optimizing Minimum Order Quantity (MOQ) models, which align Lean principles with inventory management by reducing excess stock and waste, thus enhancing cost efficiency and supporting sustainable operations (Dekier, 2012).

In the framework of Lean Management, Taiichi Ohno conceptualized "waste" as any action that fails to add value to the process, product, or end customer. This led to the formalization of the "7 Wastes" methodology, which identifies and categorizes common sources of inefficiency in production systems. These wastes include (Ohno, 1988; Liker, 2004):

- Overproduction – production of more than required by the client which leads to increase in inventory, followed by additional inventory costs and risk of products going out of date.
- Inventory – excessive stocks of raw materials, semi-finished products or finished products are tied up capital that could be used more effectively in other areas of the business.
- Overprocessing – performing activities that do not add value to the product from the customer's perspective, such as additional testing or corrections that are not necessary.
- Motion – unnecessary movement of workers or tools in the production process, which increases the time it takes to complete tasks and reduces efficiency.
- Waiting – downtime caused by waiting for deliveries of materials, tools or information, which delays the production and delivery process.
- Defects – producing defective products that require correction or total rejection, which generates additional costs and delays.
- Transport – the unnecessary movement of products or materials between different locations in a production facility, which adds no value to the product but increases production costs and time.

3. Methods

The article uses the process of literature review enabling the identification of current state of researched area. Literature review is a systematic process of gathering, evaluating and synthesizing existing research on a particular topic or question. This type of review aims to provide a comprehensive summary of current knowledge, identify trends, and recognize gaps in the research. Unlike systematic reviews, which follow a rigorous, pre-defined methodology, regular literature reviews offer more flexibility in selecting and analyzing sources, allowing for broader coverage of the topic (Machi, McEvoy, 2021). In the initial stages, a literature review begins with formulating a research question to guide the review process. From there, sources are identified through systematic searching of academic databases, such as Scopus, Web of Science, and Google Scholar, and other relevant sources. The chosen source was Web

of Science and the time frame covered the publications up until June of 2024. After selecting the literature, each study is critically analyzed for its methodology, findings, and relevance to the research question.

Based on the above, the aim of the article was to classify scientific research on the problem of MOQ optimization.

In the context of conducting a systematic literature review, two key research questions were developed:

- I. What are the current MOQ models that focus on optimization published in the literature?
- II. Which of the "7 wastes" have been addressed or mitigated by the available MOQ optimization models?

In the Figure 1 bibliometric analysis methodology for the study done for the paper is presented.

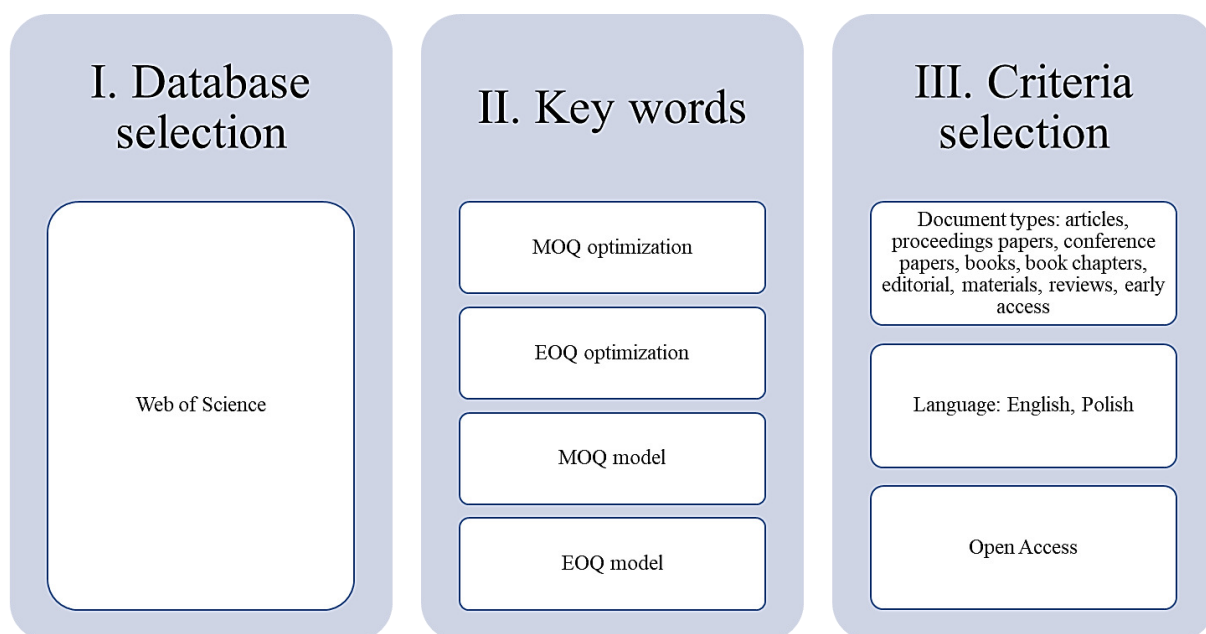


Figure 1. Bibliometric analysis methodology.

Source: author's own study.

As per fig. 1 for the first step bibliographic sources were selected. Web of Science (WoS) was taken under consideration as the leading citation indexing and research discovery platforms that offers valuable insights and performance statistics for academic publication. The WoS indexes over 34 000 journals across various disciplines and regions, but also includes books, conference proceedings and other types of academic documents.

The selection of key terms, such as Minimum Order Quantity (MOQ) and Economic Order Quantity (EOQ), is often based on their practical relevance in inventory management. Although MOQ and EOQ address different aspects of order quantities, they are sometimes mistakenly used interchangeably due to their apparent similarities in optimizing supply chain processes. MOQ refers to the minimum quantity of a product that must be ordered to satisfy production or supplier requirements, whereas EOQ is a formula used to determine the optimal order quantity

that minimizes total inventory costs. The initial search for literature involved the use of phrases such as 'MOQ optimization' and 'MOQ model' within full-text documents, followed by a subsequent search incorporating 'EOQ' to expand the scope.

To refine the scope of the search, a set of eligibility criteria was applied. The search was restricted to publications that met the following conditions: a) openly accessible; b) available in English and Polish; c) comprising articles, conference papers, books, book chapters, reviews, editorials, and early access publications. Excluded from the search were withdrawn publications, conference reviews, short surveys, notes, errata, and letters.

4. Results and discussion

The screening process of Web of Science aimed to identify models optimizing MOQ, and not only mentioning it as a factor. The revision concluded with 2 linear and 3 nonlinear optimization MOQ models. The linear models are “Effective control policies for stochastic inventory systems with minimum order quantity and linear cost”, “Two-level supply chain with order quantity constraints”, and the nonlinear are model “SSMR”, model “OWMR” and “MOQ and Batch ordering” model.

One of the linear models analysed is Inventory management model. Inventory management name was implemented for the purpose of this paper, however the original name is *Effective control policies for stochastic inventory systems with minimum order quantity and linear cost*. This model was developed based on a periodic review of the stock of a single product. This model assumes that the retailer has the ability to place an order at any stock level with an order quantity equal to or higher than the minimum order quantity MOQ M . Inventory management model assumes in the first step that at the beginning of the adopted period of time, the retailer reviews the stock and places an order with its supplier. At the end of this period, the order is fulfilled and the retailer covers the demand of its customers. If the retailer's stock level is not sufficient to cover all customer demand, the demand generated after the stock is depleted is considered as a backlog.

Inventory Management model (eq. 1) utilizes the assumptions of Markov's chain and (s, t) policy, where “ s ” stands for reorder point and “ t ” stands for time interval (Zhou et al., 2007).

$$p_{i,j} = \begin{cases} P_{(i-j)^+} & \text{for } j = t + 1, t + 2, \dots, s + M - 1, \forall i = t + 1, \dots, t + M \\ \sum_{k=i-s}^{+\infty} p_k + p_{(i-j)^+} & \text{for } j = s + M, \forall i = t + 1, \dots, t + M \\ p_{i-j+M} + p_{(i-j)^+} & \text{for } j = s + M + 1, s + M + 2, \dots, t + M, \forall i = t + 1, \dots, t + M \end{cases} \quad (1)$$

where:

$p_i = P(D=i)$;

$p_{(i-j)^+} = p_{i-j}$, if $i \geq j$, zero in any other cases;

M – minimum order quantity (MOQ);

k, i, j – based on equation assumptions (that is: $k=i-s$ in case of $p_k + p_{(i-j)^+}$, while values i and j are different for each assumption and depend on parameters t, s and M);

t – time interval;

s – reorder point.

By focusing on managing the inventory levels, controlling the reordering and considering probabilistic demand model aims to optimize the waste of excess inventory. Markov's chain approach with an (s, t) policy ensures that the inventory levels are within the optimal bounds, which means that there shouldn't be overstocking nor understocking. Reorder point and time interval incorporated by (s, t) policy helps the system to decide on reorder volume and time. Such system suggestion is crucial when MOQ is the inventory building component. Thanks to Markov's chain use the Inventory Management model is not constrained with demand fluctuations. Markov's chain allows for probabilistic modelling of demand improving the alignment of inventory with demand variability.

Model "Two-level supply chain with order quantity constraints" defines an objective function as the sum of total revenues and total costs over a specified time horizon. The model assumes that lead time between the manufacturer and the retailer is negligible and that product shortages may occur. Additionally, it is assumed that the retailer's order sizes must be placed in fixed quantities, and demand for each product is known but variable. Demand in each analyzed period is continuous, with no transportation constraints, meaning that a sufficient number of vehicles is available to fulfill all deliveries.

The mathematical representation of the "Two-level supply chain with order quantity constraints" model is presented in eq. 2.

$$\begin{aligned}
 & \sum_t \sum_i \sum_j X_{ijt} * (1 - P_{ij}) * S_{g(ij)} + \sum_t \sum_i \sum_j X_{ijt} * P_{ij} * S_{d(ij)} - \sum_t \sum_i \sum_j X_{ijt} \\
 & * b_{ij} - \sum_t \sum_j O_j * Y_{jt} \\
 & - \sum_t \sum_i \sum_j X_{ijt} * v_i \\
 & - \sum_t \sum_i \sum_j Z_{ijt} * y_{ijt} * \beta_{ij} * (Q_{\min(i,j)} - X_{ijt}) \\
 & - \sum_j \sum_t E_{jt} * A_j - TC(H) - TC(L)
 \end{aligned} \tag{2}$$

where:

i – product variable;

j – supplier variable;

t – time period;

X_{ijt} – given order volume of product i at supplier j withing time period t ;

P_{ij} – average percentege of products i defected in particular production batch at supplier j ;

$S_{g(ij)}$ – unit price of non-defective product i produced by supplier j ;

$S_{d(ij)}$ – unit price of defective product i produced by supplier j ;

b_{ij} – market price of product i from supplier j ;

$TC(H)$ – total holding period for all products;

$TC(L)$ – business losses;

Z_{ijt} – a binary variable defining the cost of reducing the order quantity (if the retailer places an order for product i from supplier j at time t with a batch size smaller than the minimum order quantity set by supplier j , then $Z_{ijt} = 1$; otherwise $Z_{ijt} = 0$);

O_j – the cost of ordering from a supplier j regardless of the type and quantity of products;

Y_{jt} – a binary variable specifying whether the order is fulfilled by supplier j (if the order is fulfilled by supplier j $Y_{jt} = 1$; otherwise $Y_{jt} = 0$);

v_i – inspection cost per unit of product i ;

y_{ijt} – a binary variable specifying whether the order for product i is fulfilled by supplier j (if the order is fulfilled by supplier j $y_{ijt} = 1$; otherwise $y_{ijt} = 0$);

β_{ij} – the cost of reducing the order quantity per unit of product i determined by each supplier j ;

$Q_{min(i,j)}$ – minimum order quantity for product i set by supplier j for each period;

E_{jt} – number of shipments sent from supplier j in period t ;

A_j – fixed transportation cost for each vehicle shipped from supplier j .

The model considers several factors outlined in Equation 2, where the total cost of a production run is calculated as the combined cost of non-defective and defective products. From this sum, costs associated with ordering, quality checks, volume reduction, transportation, inventory holding, and potential business losses are subtracted (Gorji, 2014). The “Two-level supply chain with order quantity constraints” model components aligned with the 7 Wastes framework primarily highlight inefficiencies related to inventory, defects, and transportation.

One of the nonlinear models found in the literature is model SSMR. The model provides a mathematical approach to determining the optimal order quantity, lead time, safety stock levels for buyers, and the number of shipments within a production cycle between the manufacturer and buyers. This optimization aims to minimize the total expected cost per unit of time in the producer-buyer relationship, while meeting the requirements of the Service Level Commitment (SLC). The total expected production cost includes ordering and inventory holding costs, costs related to potential failures during order fulfillment borne by all buyers, as well as setup and inventory holding costs on the manufacturer’s side.

SSMR model ensures cost efficiency and reliability in the supply chain by optimizing key logistical and financial elements, ultimately supporting a sustainable, service-oriented production framework.

The total expected cost per unit of time for the SSMR model is the sum of the total expected costs incurred by both the retailers and the supplier. The SSMR model is represented by equations 3 and 4.

$$JTEC(Q, k_1, k_2, \dots, k_N, L_1, L_2, \dots, L_N, m) = \sum_{i=1}^N TEC_{bi}(Q, k_i, L_i) + TEC_v(Q, m) \quad (3)$$

and

$$\begin{aligned} JTEC(Q, k_1, k_2, \dots, k_N, L_1, L_2, \dots, L_N, m) \\ = \frac{D}{Q} \left[\frac{A_v}{m} + \sum_{i=1}^N (A_{bi} + C_i(L_i)) \right] \\ + \sum_{i=1}^N \left[h_{bi} C_{bi} \left(\frac{Q}{2D} D_i + k_i \sigma_i \sqrt{L_i} \right) \right] + \frac{Q}{2} h_v C_v \left[m \left(1 - \frac{D}{P} \right) - 1 + \frac{2D}{P} \right] \end{aligned} \quad (4)$$

where:

JTEC –Joint Total Expected Cost;

Q – batch size per shipment, necessary to meet the demand of all buyers;

k_i – safety factor, a multiplier used to set the level of additional inventory required to minimize the risk of stockouts due to demand variability and supply chain uncertainty;

L_i – lead time for delivery;

m – number of batches supplied from the producer to each buyer within the production cycle;

N – number of retail sellers;

TEC_{bi} – total expected cost per unit time for the i -th buyer;

TEC_v – total expected cost per unit time for the producer;

D_i – average demand per unit time;

A_v – production setup cost for each configuration;

A_{bi} – order cost for each order;

h_{bi} – inventory holding cost per unit time for retail seller;

C_{bi} – purchase cost per unit for the retail seller;

P – production rate;

h_v – inventory holding cost per unit time for the producer;

C_v – purchase cost per unit for the producer.

Equation 3 expresses the expected total cost as the sum of costs for all buyers and producers, based on variables like batch size Q , safety factors k_i , lead times L_i , and the number of batches m . The expected cost for each individual buyer i is influenced by the batch size Q , safety factor k_i , and lead time L_i . Meanwhile, the producer's expected cost depends on the batch size Q and the number of deliveries m .

Equation 3 further expands into equation 4, which dissects the joint total expected cost (JTEC) into its individual components. Equation 4 summarizes the costs associated with ordering and holding inventory for each buyer i , scaled by demand D and batch size Q , including storage, safety stock, production, and delivery costs. This layered approach allows the model to identify cost optimization opportunities across the supply chain, balancing production, ordering, and inventory strategies to minimize overall costs (Jha, Shanker, 2013).

To determine the total expected cost, situations involving stockouts for retail sellers were not considered. Stockout costs are challenging to estimate due to the influence of intangible factors, such as loss of reputation and delays in subsequent supply chain stages. Through various variables, the SSMR model aims to balance storage, ordering, and production costs while minimizing the total expected cost across the entire supply chain.

Another nonlinear model that deals with optimizing the minimum order quantity is the OWMR model. The OWMR model is designed around a two-level inventory system with one warehouse and multiple retailers (OWMR). The model assumes that retailers receive orders from customers at independent times. If the demand cannot be met immediately, retailers place an order and replenish the inventory from the warehouse (level 1), which in turn replenishes it from an external supplier (level 2). In the case of the OWMR model, a warehouse is not just a room for storing inventory. The warehouse is an intermediary between the supplier and the retailers, receiving orders from retailers and then processing them into orders for the supplier. It is also assumed that there is a delay between orders and deliveries at each stage.

Equation 5 provides the formal mathematical formulation of the OWMR model (Huaxiao et al., 2019).

$$L(S_0, S_1, \dots, S_N) = \sum_{y=S_0}^{S_0+M-1} \sum_{q \geq M} Prob(Y = y, Q = q) \sum_{k=0}^{q-1} C(y - k, S_1, \dots, S_N) \quad (5)$$

where:

$L(S_0, S_1, \dots, S_N)$ – the average cost;

M – minimum order quantity, MOQ;

S_0 – agreed stock level parameter for the warehouse;

S_i – agreed stock level parameter for the retailer;

Y_n – inventory level after placing an order within n time;

$C(y-k, S_1, \dots, S_N)$ – storing cost in single time period for single retailer when inventory is $(y-k, S_1, \dots, S_N)$;

q – order volume;

y – inventory level.

The equation 5 represents the average cost as a sum over various inventory levels and orders. It is equal to a double sum; the first sum iterates over all possible inventory levels y in the central warehouse, starting from a value S_0 (the initial inventory level for the warehouse)

up to S_0+M-1 , where M is the minimum order quantity (MOQ); the second sum iterates over the order quantity q , which must be at least equal to MOQ M . The probabilistic part of the equation represents the probability that the inventory level Y is y and that the order quantity Q is q . This probability takes into account random changes in demand and order quantity that may result from market dynamics. The expression $y-k$ represents the inventory level after taking into account changes in inventory (for example, reductions due to sales or deliveries). In practice, the purpose of equation 5 is to balance the costs of ordering, storage, and potential losses, while taking into account variable demand and lead times.

The model minimizes the total cost of inventory management by optimizing the order size and managing inventory levels in a probabilistic manner that is responsive to changing demand. By taking into account probabilities and minimum order sizes, the model allows for achieving a balance between storage costs and ordering costs, which is crucial for effective supply chain management.

The nonlinear model, which for the purposes of this work is called the MOQ and Batch Ordering model, i.e. ordering in batches (originally called Effective inventory control policies with a minimum order quantity and batch ordering), considers a system of periodic inventory review for a single product with irregular demand. The retailer replenishes inventory from the supplier, and its order must meet stated conditions. One is that it should be a specified minimum quantity M (i.e. MOQ) and the other is that it should be a multiple of the established batch of orders Q (i.e. Batch Ordering).

The model assumes that M is an integral multiple of Q and that M is greater than Q . The retailer places an order after analysing the status of its inventory. After placing the order, the supplier fulfills the demand, and in the event of failure to fulfill the order, it is recorded for later production. In the last step, the cost of holding inventory is calculated, taking into account the costs of storing excess inventory and penalties for failure to fulfill the order (Zhu et al., 2015).

Mathematical formulation of the MOQ and Batch Ordering model is provided by equation 6.

$$C_n(y_n) = h\mathbb{E}[(y_n - D_n)^+] + p\mathbb{E}[(D_n - y_n)^+] \quad (6)$$

where y_n and D_n are integers, and:

$C_n(y_n)$ – total costs;

$\mathbb{E}$ – expected value;

h – storage cost;

y_n – stock after placing an order in a specified time period n ;

x_n – stock before placing an order in a specified time period n ;

D_n – demand in a specified time period n ;

p – penalty cost per unit in a specified time period.

The cost function (eq. 6) enables optimization and waste reduction by balancing holding cost and shortage (or penalty) costs. Holding cost component captures the expected cost of holding surplus inventory at the end of period n , where y_n is the inventory after placing an order and D_n is the demand in period n . Minimizing this cost prevents excessive stock accumulation, which is critical for reducing waste. Storage cost component accounts for the penalty cost when demand exceeds inventory, representing the expected cost of stockouts. By including this penalty, the model discourages understocking, ensuring a balance between inventory availability and minimizing overstock. In general MOQ and Batch ordering model provides a mathematical approach to optimizing inventory while simultaneously minimizing waste by balancing the key costs associated with both overstock and shortage situations.

The collection of MOQ optimization models addresses several of Taiichi Ohno's "7 wastes". Each model is designed to calculate the total production run costs for suppliers and/or retailers, focusing on different drivers of waste. In the Figure 2 shows specific wastes included in the MOQ models.

	Over production	Inventory	Over processing	Motion	Waiting	Defects	Transport
Effective control policies for stochastic inventory systems with minimum order quantity and linear cost		X					
Two-level supply chain with order quantity constraints		X				X	X
Model SSMR		X					
Model OWMR		X					
MOQ and Batch Ordering model		X					

Figure 2. Types of wastes included in selected MOQ models.

Source: author's own study.

Figure 2 provides an overview of the '7 wastes' and highlights the models analysed, using an "X" to indicate which wastes each model addresses. From this overview, it is clear that inventory waste was a primary focus, appearing in all five models reviewed. Additionally, the two-level supply chain model with order quantity constraints also considers defects and transportation waste alongside inventory.

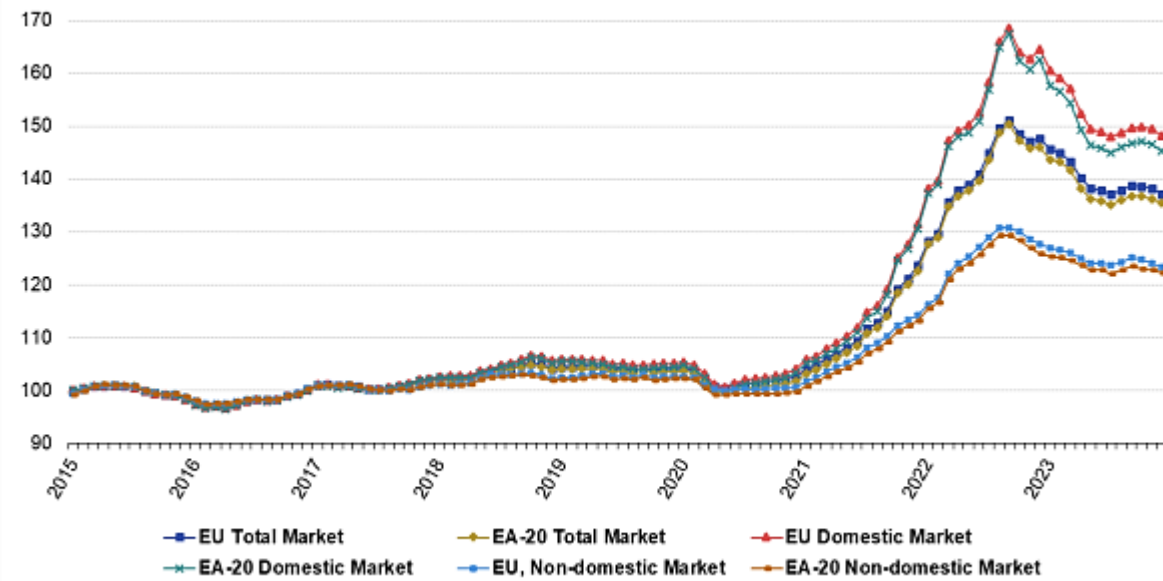
Considering the findings of focus to optimize costs driven by inventory, defects and transportation, it is worthwhile to examine the potential explanations and underlying mechanisms. To illustrate global trends driving the need for cost optimization tools, graphs from Eurostat and Trading Economics are used to show rising industrial production prices. Implementing MOQ optimization models is thus a logical step for manufacturers seeking to manage and control these costs. By optimizing order quantities, manufacturers can reduce excess inventory expenses, a major component of production costs. Notably, MOQ models also target defects, addressing quality issues alongside cost-efficiency and reducing waste from defective products, ultimately contributing to a more streamlined and cost-effective manufacturing process.

Manufacturing cost management is increasingly complex and essential globally, so it's no surprise that researchers are intensifying efforts to optimize these expenses. Key cost drivers include rising environmental and transportation costs, ongoing supply chain disruptions, and a growing emphasis on sustainable practices in inventory management (Pattnaik et al., 2021; Dalhousie University, 2023). Cost management for manufacturing has become increasingly intricate due to a variety of factors that directly impact operational efficiency and profitability. Rising industrial production and gasoline prices, for example, elevate both production and transportation costs, which can lead to excess inventory holding and distribution inefficiencies if not managed carefully. Additionally, increased emphasis on sustainability compels companies to reduce defects and optimize resources, further highlighting the relevance of MOQ optimization models. By addressing these specific areas of waste (such as minimizing excess inventory, reducing transportation costs, and preventing defects) MOQ models enable manufacturers to adapt to cost pressures while maintaining lean, sustainable operations (Nayak et al., 2021).

To further support above tendencies, Figure 3 presents relevant data from Eurostat regarding the industrial producer prices increasing trend.

Figure 3 presents an overview of changes to producer prices since 2015. The Y-axis represents the Industrial Producer Price Index (PPI), which is a relative measure where 2015 is set as the base year (2015 = 100). This index shows the price level changes in industrial products over time, with values above 100 indicating if prices have risen compared to the 2015 baseline and values below 100 showing a decrease. Axis X displays time, specifically the years from 2015 to 2023. Analysed period of time shows clear increasing trend in prices regardless of market kind. Types of markets shown on the graph are EU Total Market, EA-20 Total Market, EU Domestic Market, EA-20 Domestic Market, EU Non-domestic Market, EA-20 Non-domestic Market (Eurostat, 2024). This increasing trend in industrial producer prices underscores the need for companies to enhance profitability by optimizing their operational processes. One effective approach is the implementation of Minimum Order Quantity (MOQ) optimization models, which help organizations manage inventory more efficiently, reduce waste, and offset rising production costs.

EU, EA-20 Industrial producer prices, total, domestic and non-domestic market, 2015 - 2023, undadjusted data (2015 = 100)



Note: y-axis does not start at 0

Figure 3. EU, EA-20 Industrial producer prices, total, domestic and non-domestic market, 2015-2023.

Source: Industrial producer price index overview, Eurostat.

Recent findings indicate that the cost of warehousing and inventory has been growing due to heightened demand for storage, logistics challenges, and a push toward sustainable practices. These costs are driven partly by increased energy prices, particularly the rising costs of gasoline and diesel, which significantly impact transportation expenses. This is compounded by new regulatory requirements aimed at sustainability, making inventory management and storage more expensive overall. Studies in sustainable inventory management emphasize integrating environmental considerations into inventory practices to reduce carbon footprints and improve efficiency. Implementing Minimum Order Quantity (MOQ) optimization models supports these goals by streamlining inventory levels, reducing excess stock, and lowering associated costs (Becerra et al., 2022; Schoenberger, 2024).

The observed cost increases related to warehousing, inventory, and transportation align with the broader trend of rising gasoline prices, as shown in Figure 4. The data from Trading Economics highlights these trends, supporting the rationale for adopting optimization strategies like MOQ models to counteract rising operational costs.



Figure 4. Gasoline price changes in years 2015-2024.

Source: Trading Economics, Gasoline.

Figure 4 presents the graph of historical data of gasoline prices throughout the years 2015 till 2024. Axis Y presents the USD/Gal unit (US dollar per gallon). Within this period of time the gasoline price went up from 1.35 USD/Gal in January of 2015 to 1.96 USD/Gal in October 2024 (Trading Economics, 2024). Aside from increasing trend the gas prices are easily impacted by the geopolitical reasons. Price drop in early 2020 can be related to the COVID-19 pandemic (World Health Organization, 2020) and the spike in early 2022 to Russian invasion of Ukraine (United Nations, 2022). To such price trend of gasoline manufacturers must respond by implementing optimization solutions related with transport and logistics.

5. Summary

Minimum order quantity (MOQ) has a direct impact to waste in the concept of lean management as visible within all quoted models. The review identified five models in scientific publications addressing the issue of MOQ optimization (“Effective control policies for stochastic inventory systems with minimum order quantity and linear cost”, “Two-level supply chain with order quantity constraints”, “SSMR”, “OWMR” and “MOQ and Batch ordering”). All of these models considered the inventory. Only “Two-level supply chain with order quantity constraints” model considered defects and transport along the inventory.

A critical evaluation of these models reveals their strengths and limitations. While they offer valuable insights into reducing inventory costs and enhancing operational efficiency, their narrow focus often neglects other significant wastes identified in lean management, such as overproduction, waiting, and excess processing. This limitation underscores a critical gap in the current body of knowledge, presenting an opportunity for the development of more holistic optimization frameworks.

The study underscores the practical importance of selected models in managing rising production costs and improving efficiency. However, adapting them to modern challenges such as sustainability and global disruptions is crucial. Future research should expand their scope to include the full spectrum of the “7 Wastes”, enabling more comprehensive waste reduction strategies. This paper’s literature review finds that a focus on inventory management is especially prudent in this context. As discussed, manufacturing processes show a tendency toward rising costs. To achieve business efficiency while maintaining quality, production costs must be continually optimized. The analysed MOQ models primarily address inventory costs but also consider factors like transport and defects occurring during the production. With ongoing environmental, geopolitical, and economic changes, the supply chain will need to continuously enhance its efficiency. These dynamics will shape the future of enterprises and the evolution of new models to meet emerging demands.

Existing MOQ optimization models lay a valuable foundation but require enhancements to meet evolving supply chain demands. Expanding their applicability could advance both academic research and practical implementation, supporting more efficient and sustainable operations.

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References

1. Beccerra, P., Mula, J., Sanchis, R. (2022). *Sustainable Inventory Management in Supply Chains: Trends and Further Research*.
2. Chopra, S., Meindl, P. (2016). *Supply Chain Management: Strategy, Planning, and Operation (6th ed.)*. Pearson.

3. Dalhousie University (2023). Sustainable Supply Chain Risk Management in a Climate-Changed World: Review of Extant Literature, Trend Analysis, and Guiding Framework for Future Research. *Sustainability*, 15(17), 13199.
4. Dekier, Ł. (2012). The origins and evolution of Lean Management system. *Journal of International Studies*, 5, 1, 46-51.
5. Eurostat (02.2024). *Industrial producer price index overview*. Retrieved from: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Industrial_producer_price_index_overview.
6. Gorji, M.H., Mostafa, S., Hossein, K. (2014). Optimizing inventory decisions in a two-level supply chain with order quantity constraints. *Applied Mathematical Modelling*, 38, 3, 814-827.
7. Gupta, S., Jain, S., Benyoucef, L. (2019). Optimal ordering policy for deteriorating items under trade credit financing with minimum order quantity. *Journal of Industrial and Production Engineering*, 36(6), 369-379.
8. Huaxiao, S., Tian, T., Zhu, H. (2019). A two-echelon inventory system with a minimum order quantity requirement. *Sustainability*, 11, 18, 5059.
9. Jha, J.K., Shanker, K. (2013). Single-vendor multi-buyer integrated production-inventory model with controllable lead time and service level constraints. *Applied Mathematical Modelling*, Vol. 37, Iss. 4, pp. 1753-1767.
10. Klamerek, J., Kutnik, K. (2023). Zarządzanie ryzykiem w łańcuchu dostaw: jak minimalizować straty i poprawić efektywność transportu. *Zarządzanie Innowacyjne w Gospodarce i Biznesie*, 2/37, 163-169.
11. Li, X., Wang, H., Zhu, L. (2020). Supply chain coordination with pricing and order quantity decisions under stochastic demand and minimum order quantity constraints. *International Journal of Production Economics*, 223, 107534.
12. Liker, J.K. (2004). *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*. McGraw-Hill.
13. Liu, S., Zhang, L. (2021). A multi-objective optimization model for supplier selection with MOQ constraints and uncertain demand. *Computers & Industrial Engineering*, 152, 107007.
14. Machi, L.A., McEvoy, B.T. (2021). *The Literature Review: Six Steps to Success (4th ed.)*. Corwin.
15. Nayak, M.M., Pattnaik, S., Centobelli, P. (2021). Sustainable Perspectives: Green Supply Chain and Operations Management. *Sustainability*, 13(21), 11756.
16. Ohno, T. (1988). *Toyota Production System: Beyond Large-Scale Production*. Productivity Press.
17. Pattnaik, S., Nayak, M.M., Abbate, S., Centobelli, P. (2021). Recent Trends in Sustainable Inventory Models: A Literature Review. *Sustainability*, 13(21), 11756.

18. Schoenberger, M. (06.2024). *Global supply chain fragility: Five trends and their impact on the global economy*. KPMG.
19. Shenoy, S., Zhao, A. (2019). *Raw material minimum order quantity optimization*. MIT Center for Transportation and Logistics.
20. Trading Economics (2024). Gasoline. Retrieved from: <https://tradingeconomics.com/commodity/gasoline>.
21. United Nations (2022). *Statement on the Russian invasion of Ukraine*. Retrieved from <https://www.un.org>.
22. World Health Organization (2020). *Statement on the second meeting of the International Health Regulations Emergency Committee regarding the outbreak of novel coronavirus (2019-nCoV)*. Retrieved from: <https://www.who.int>.
23. Zhou, B., Zhao, Y., Katehakis, M.N. (2007). Effective control policies for stochastic inventory systems with a minimum order quantity and linear costs. *International Journal of Production Economics*, Vol. 106, Iss. 2, pp. 523-531.
24. Zhu, H., Liu, X., Chen, Y.F. (2015). Effective inventory control policies with a minimum order quantity and batch ordering. *International Journal of Production Economics*, Vol. 168, pp. 21-30.

CONSUMER ACTIVISM ON SOCIAL MEDIA DURING GEOPOLITICAL CONFLICT

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Purpose: This paper aims to examine the dynamics of consumer engagement and sentiment in social media activism during geopolitical conflict, focusing on how consumer activism manifests online. By analyzing user interactions and shifts in sentiment, the study seeks to offer insights into the scale and impact of digital activism, particularly how consumers mobilize on social media in response to geopolitical events. Additionally, the research aims to provide guidance on how brands can adapt their communication strategies to navigate the challenges posed by widespread digital activism effectively.

Design/methodology/approach: The research employs a quantitative sentiment analysis and qualitative content analysis of Facebook interactions. The study specifically investigates three brands from the Mulliez Group (Leroy Merlin, Auchan, and Decathlon) during the Russian-Ukrainian conflict. The analysis covers user-generated content from Polish Facebook profiles.

Findings: The study identifies a distinct pattern of consumer engagement, characterized by an initial surge in activism and negative sentiment that peaks early during the conflict before gradually stabilizing. This trend highlights the short-lived intensity of social media-driven activism, influenced by hedonic adaptation. While initial consumer responses were emotionally charged and fueled by calls for boycotts, sentiment analysis shows a decline in negative engagement towards the end of the year, indicating the effectiveness of adaptive brand communication strategies.

Research limitations/implications: The study is limited by its focus on a specific geopolitical event and a narrow sample of brands, which may affect the generalizability of the findings.

Practical implications: The findings suggest that brands can benefit from implementing transparent, adaptive, and responsive communication strategies during periods of intense consumer activism. Real-time sentiment monitoring and proactive engagement are crucial for managing public perception and mitigating negative impacts.

Originality/value: This paper contributes to the literature on social media activism and brand communication by offering a detailed analysis of consumer engagement patterns during a geopolitical crisis. The use of advanced sentiment analysis and engagement metrics provides a novel approach to understanding the temporal dynamics of online activism. The study is valuable for brand managers, marketers, and researchers interested in navigating the complexities of digital consumer behavior and crisis communication.

Keywords: consumer activism, sentiment analysis, consumer engagement.

Category of the paper: research paper.

1. Introduction

Social media due to specific affordances (Rhonzlyn et al., 2023) serves as a nexus connecting brands with their consumers (Zeng et al., 2022). Communication via separate brand accounts on social media allows one to build long-term or short-term relationships with current and potential consumers through parasocial interactions - PSI (Hartmann and Goldhoorn, 2011). PSI are defined as a concept meaning an illusory sense of social connection resulting in specific relationships, and loyalty with (social) media personalities and entities, widely perceived as brands (Labrecque, 2014; Jia et al., 2024). The interactivity of social media (the ability to establish and maintain a mutual relationship through specific interactive cues; Ma et al., 2022) is one of the factors facilitating the creation and inclusion of PSI in the brand-consumer relationship (Kim et al., 2021). Brands perceived as highly interactive on social media significantly improve their sales opportunities, level of customer knowledge and satisfaction, and build networks of loyal customers (Bozkurt et al., 2021). Simultaneously, content created and shared by brands - Marketer Generated Content (MGC), directly or indirectly associated with a brand or product (Qian et al., 2022) - influences the cognitive, emotional, and behavioural activities of recipients (Ma et al., 2022), and overall consumer brand's attitude - the position expressed by the consumer based on a set of arguments, emotions, knowledge (Kuehn et al., 2019; Zhang et al., 2024). Social media also enable users to immediately react to reports about the crisis and its effects (Schultz et al., 2011).

Social media platforms have become crucial spaces, where individuals not only fulfill personal needs like information exchange and social interaction but also exert influence on each other (Grover et al., 2022). This digital engagement has become integral to individuals' online presence, particularly in expressing opinions on socio-political issues (Anderson et al., 2018; Grover et al., 2022).

Social media activism often utilize hashtags to signal participation and build communities of support among like-minded individuals (Johnson et al., 2019). These platforms also provide avenues for social influence, allowing users to share opinions and shape others' perspectives on specific products or brands (Boulianne, 2015; De Zúñiga et al., 2014).

This study delves into the dynamics of the consumer engagement in the social media activism. Specifically examining Polish users of Facebook, whose interest is heightened due to Poland's significant intake of Ukrainian refugees and historical ties with Russia, we analyze public reactions to the Mulliez Group's decision to maintain its Russian operations. Utilizing sentiment analysis, our methodology unveils an understanding of evolving brand-consumer relationships, characterized by the transient nature of social media activism.

While initial boycott engagements are emotionally charged and propelled by social media's mobilization capabilities, their impact tends to stabilize over time due to shifts in public attention and corporate responses. This transition underscores the importance for companies to

engage in empathetic and proactive communication, directly addressing the underlying concerns fueling boycotts.

2. Consumer activism on social media

Consumer activism, particularly on social media, has emerged as a powerful force that allows individuals to hold companies accountable for their business practices. Traditionally, consumer activism was understood as a form of resistance where individuals or groups sought to pressure corporations into adopting more ethical or socially responsible behaviors (Friedman, 1999; Garrett, 1987). The primary goal of this activism is to influence corporate actions through tactics like boycotts, public campaigns, and petitions (Smith, Cooper-Martin, 1997). With the rise of digital platforms, the nature of consumer activism has shifted significantly, enabling rapid mobilization and the ability to reach a broader audience. This transformation highlights the dynamic and evolving character of consumer activism in the digital age.

Social media engagement plays a critical role in shaping consumer activism, providing an interactive platform where users can share information, discuss concerns, and coordinate collective actions. Engagement on social media can be divided into internal and external interactions. Internal engagement occurs within an individual's own social network, while external engagement involves interactions within the social space of others (Fredricks, Blumenfeld, Paris, 2004).

The engagement process is often multidimensional, encompassing behavioral, cognitive, and emotional aspects. Behavioral engagement includes actions such as liking, sharing, and commenting, reflecting an active involvement in online discussions. Cognitive engagement involves the mental effort and attention users dedicate to processing social media content, while emotional engagement relates to the affective reactions users experience, such as anger or joy, which can drive activism (Kietzmann et al., 2011). These varied forms of engagement help amplify consumer voices and facilitate the spread of activist messages on social media platforms.

The emergence of social media has revolutionized the landscape of consumer activism, turning it into a more dynamic form of digital activism. Social media platforms like Facebook, Twitter, and Instagram allow consumers to instantly share grievances and coordinate large-scale movements, which can quickly gain momentum and reach a global audience. The efficiency and cost-effectiveness of digital platforms have made it easier for consumer-led movements to gain traction (Sen et al., 2001). The interactive and community-building features of social media enable activists to form supportive networks, enhancing the impact of their campaigns and solidifying the sense of a shared purpose (Kaplan, Haenlein, 2012). The Social Media Honeycomb model further illustrates how elements such as identity, sharing,

and conversation play a role in facilitating the mobilization of digital activism (Kietzmann et al., 2011).

Boycotts represent a central tactic in consumer activism, often serving as a collective method for consumers to express discontent and pressure companies into making changes (Garrett, 1987; Klein, 2003). The rise of digital platforms has transformed traditional boycotts into highly organized, large-scale digital movements. Online boycotts leverage the reach of social media, making it easier for activists to coordinate their efforts, raise awareness, and encourage widespread participation (Yuksel, Mryteza, 2009). Research by Sen et al. (2001) highlights the effectiveness of digital boycotts due to their viral nature, where boycott calls can rapidly spread across networks. This shift illustrates how digital activism has amplified traditional resistance tactics, turning localized efforts into global campaigns with significant implications for the targeted brands.

The power of consumer boycotts has been well-documented in the literature, demonstrating their potential to impact both the financial performance and brand image of targeted companies. Chavis and Leslie (2009) investigated the effects of politically motivated boycotts and found a significant decline in sales for affected companies. Boycotts serve not only as a tool for collective resistance but also as a means for consumers to express ethical and political values through their purchasing decisions (Jae, Jeon, 2016). This shift towards values-based consumption underscores the increasing influence of consumer activism as a mechanism for social control and a driver of corporate accountability (Klein et al., 2004).

In recent years, the role of the Internet and social media in consumer boycotts has attracted growing scholarly attention. The advantages of the Internet, including its speed and wide accessibility, have made online boycotts an effective mechanism of consumer activism (Sen et al., 2001). Koku (2012) noted that the widespread use of the Internet warrants examining both the tactics consumers use to mobilize against companies and the strategies companies can employ to counteract these movements. Studies by Pöyry and Laaksonen (2022) have shown that social media provides a powerful platform for articulating consumer dissatisfaction, underscoring the importance of understanding digital boycott dynamics for both activists and businesses.

Overall, consumer activism on social media has become an influential force capable of shaping brand narratives and driving corporate change. The interconnected nature of social media allows for efficient organization of collective actions, making it crucial for companies to adopt robust engagement and crisis management strategies (Lokhande, Natu, 2022). Recent studies by Sun et al. (2021) and Bronnenberg & Dubé (2022) have demonstrated the substantial impact that consumer-driven campaigns can have on brand reputation and financial performance. As digital activism continues to grow, companies must acknowledge the power of consumer engagement on social media and leverage this understanding to foster dialogue, address concerns, and align their practices with evolving consumer expectations, ultimately turning challenges into opportunities for positive change.

3. Research method

Our research methodology centered on evaluating consumer engagement and sentiment on Facebook, particularly within online movements. Specifically, we chose to focus on three brands under the Mulez family brand group: Leroy Merlin, Auchan, and Decathlon. These brands, according to available information, continued operations in Russia during the initial phase of the armed conflict and became prominent targets of consumer actions.

To align with the methodological rigor advocated by Kozinets (2002), we carefully selected the communication platform, opting for Facebook due to its prevalence among Polish-speaking consumers. Our analysis encompassed content shared by Polish-speaking users on Facebook from the onset of the conflict, spanning from February 24th to December 31st, 2022. In total, we analyzed 4615 Polish Facebook profiles.

This research was divided into two sections. The first section focused on the analysis of the Facebook profiles of three brands from the Mulliez Group, examining total user engagement (Interactivity Score), average user engagement (Engagement Score), and the sentiment expressed in comments (Sentiment Score). Each metric was designed to provide a nuanced understanding of user engagement and sentiment across social media interactions.

1. **Interactivity Score:** This metric evaluates the overall engagement level of a brand's social media profile, encompassing all user interactions, including reactions (e.g., like, love, ha-ha, sad, angry, wow), comments, and shares. The Interactivity Score reflects the relative performance of the analyzed profile compared to a representative sample of over 4000 Polish Facebook profiles from various industries. The score is standardized on a scale from 0 to 100, where a higher score indicates greater overall user engagement. A score of X implies that the weighted total of interactions (Interactivity Index - INI) for the brand's profile exceeded that of $X\%$ of the sampled Polish Facebook profiles during the given period.
2. **Engagement Score:** This indicator measures the effectiveness of individual content posted by a brand, calculated as the average engagement per post (Interactivity Index - INI). Unlike the Interactivity Score, which considers total engagement, the Engagement Score emphasizes the quality of content by rewarding profiles that generate significant interaction despite a lower posting frequency. The score is standardized on a scale from 0 to 100, and a score of X indicates that the average engagement per post for the analyzed profile was higher than that of $X\%$ of the sampled Polish Facebook profiles, reflecting its relative content quality and resonance with the audience.
3. **Sentiment Score:** The Sentiment Score quantifies the emotional tone of user discussions under posts on a brand's social media profile. Utilizing an artificial intelligence algorithm, this metric assesses the sentiment of user comments, categorizing them as positive, neutral, or negative. The Sentiment Score ranges from

0 to 100, where a score of 0 indicates exclusively negative comments, and a score of 100 reflects purely positive comments. A score of 50 represents a balanced sentiment, with equal proportions of positive and negative comments. This metric provides a direct measure of public sentiment, highlighting consumer attitudes towards the brand in the context of online discussions.

The sentiment analysis model in this study categorized social media posts and their comments into three sentiment classes: Neutral, Positive, and Negative. Neutral posts lacked a clear sentiment or had balanced positive and negative expressions, while positive and negative posts displayed explicit sentiments. The analysis began with text preprocessing, where content was tokenized into words and meaningful symbols. Texts were then represented as vectors using the "FastText" algorithm, tailored specifically for the informal language of social media, unlike traditional models that rely on formal text sources.

These vector representations were fed into a neural network model, specifically a BiGRU (Bidirectional Gated Recurrent Unit) for Polish-language texts. The model determined the sentiment by evaluating the probability of each class and selecting the one with the highest likelihood. This vector-based approach captured the context of the words, providing more accurate sentiment analysis that accounts for the nuances in social media language.

The second section analyzed online mentions of these brands, with a focus on the content of these mentions. We employed content analysis to categorize the discourse, aiming to identify recurring themes behind consumer engagement in the social media activism (Hsieh, Shannon, 2005). Particular attention was given to those related to the war, especially mentions calling for boycotts. The mentions categorization was done in two stages. Firstly the content was grouped into two categories: War-related and Other. Then, the first part of data (concerning war) was divided into three subcategories: Boycott, Exit from Russia and Other. As a result, more than 340.000 mentions from February 24th to December 31st, 2022, were included in the analysis.

4. Results

An analysis of the number of comments shows that the number of comments starts to increase immediately after Russia's aggression against Ukraine on February 24th, reaches a clear peak in March, and then starts to decrease with varying dynamics until the end of April or May (Figure 1). Simultaneously, the number of comments with negative sentiment compared to those with a positive sentiment is highest in this interval, which may indicate that users' involvement was in line with their attitude. At the same time, the corresponding period coincides with a decrease in brand activity, particularly between April and the end of May, when the number of profile posts generated by the brands themselves slowly starts to increase while the interest of users in commenting decreases.

Number of user comments

February - December 2022

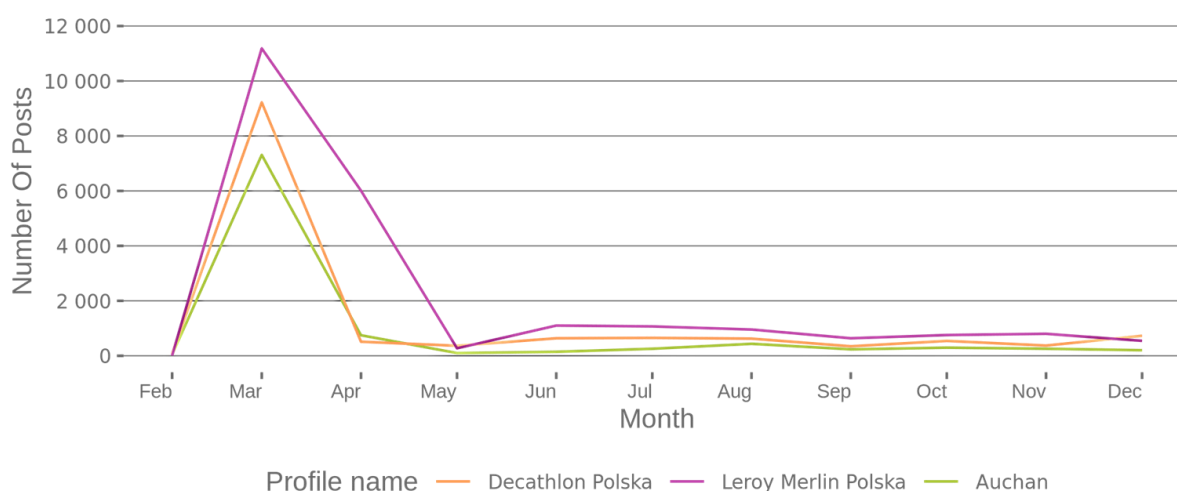


Figure1. The number of use comments.

The Sentiment Score analysis (Figure 2) reveals a dominant trend of negative sentiments across all three brands: Decathlon Poland, Leroy Merlin Poland, and Auchan. Despite slight variations, the sentiment scores hover around the 30-point mark, with Decathlon Poland slightly exceeding the average at 33, while Leroy Merlin Poland aligns closely with the average score of 30, and Auchan falls below at 26. This proximity to the 30-score threshold underscores a generally unfavorable consumer perception, indicating a significant prevalence of negative sentiment across social media discussions related to these brands.

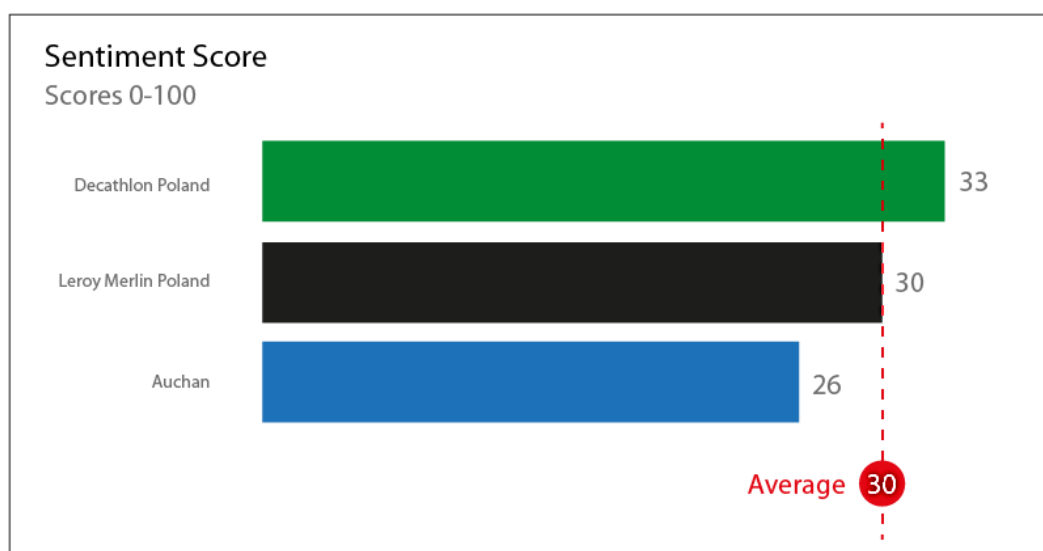


Figure 2. Sentiment Score.

Throughout the period, Decathlon Polska consistently exhibits higher sentiment scores compared to the other two brands, showing an upward trend towards the end of the year. In contrast, Leroy Merlin Polska generally demonstrates lower sentiment scores, with a notable dip in March (Figure 3). In March 2022, coinciding with the escalation of the Russian-Ukrainian conflict, a stark decline in Sentiment Scores was noted. This period saw an outpouring of negative commentary, pushing for the brands to halt their operations in Russia, reflecting a palpable public discontent. The overall trend indicates a slight improvement in sentiment for all three brands by December. By year-end, the proportion of negative comments had reduced, suggesting a gradual diminishing of the boycott's impact on brand reputations. This trend highlights the fluid nature of public sentiment in the digital age, where initial uproars can eventually give way to a more balanced discourse.

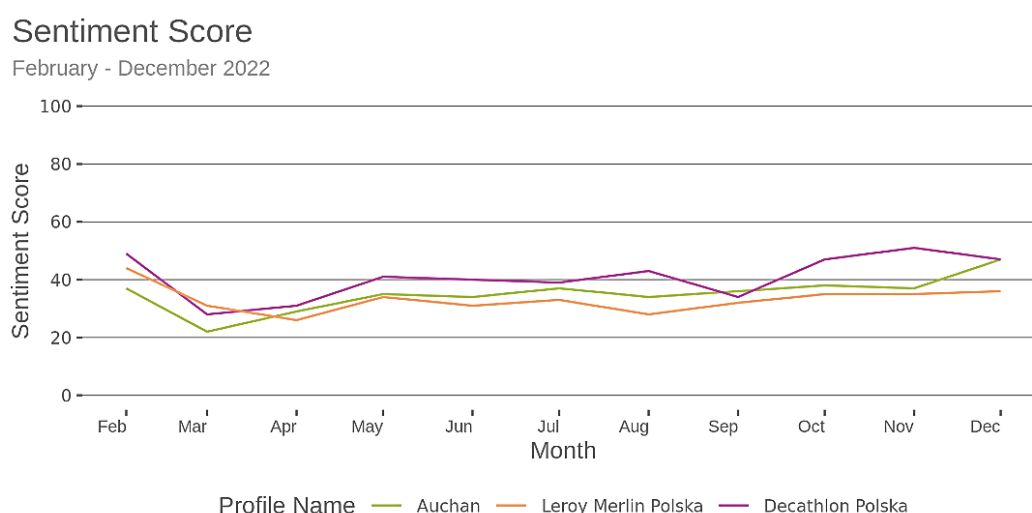


Figure 3. Sentiment Score divided by months.

The phenomenon of social media activism was reflected even more strongly in the Engagement Score, i.e. the engagement around individual posts. Between 24 February and 31 December 2022, content on the Leroy Merlin profile attracted the most attention; it generated more activity on average than posts from 87% of profiles on Polish Facebook. This high result was also influenced by the lack of breaks in the brand's communication. In second place was Auchan's profile with an Engagement Score of 73, and in last place was Decathlon with content engaging more than the posts of 63% of Facebook profiles (Figure 4). The lower score on Decathlon's profile was the result of a large number of user posts on the brand's page (which was a reaction to the shop's lack of clarity on its Russian operations).

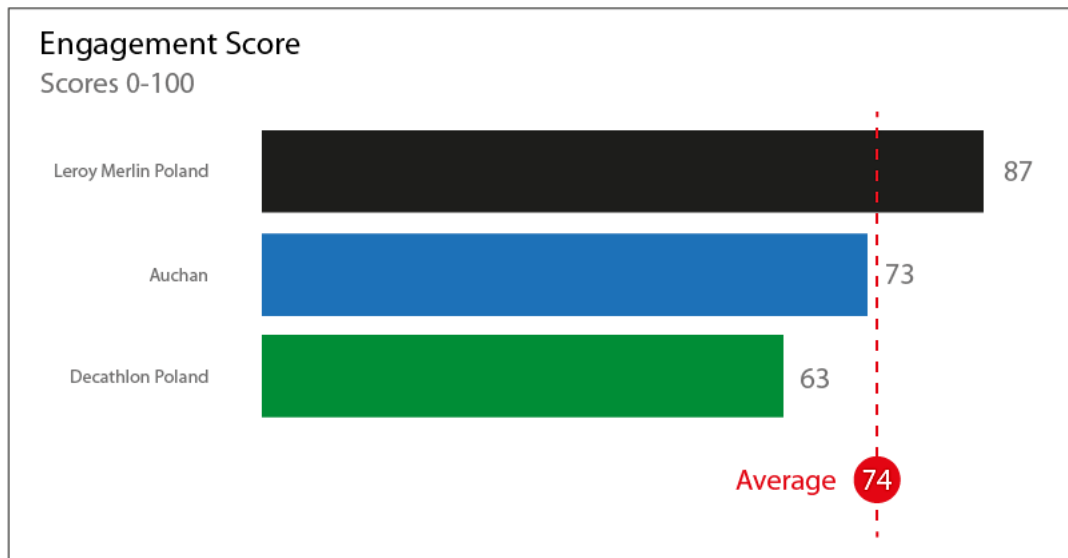


Figure 4. Engagement Score.

At the end of February 2022, after the outbreak of the war in Ukraine, only two posts were published on Leroy Merlin's profile, which accumulated very high engagement (there were then hundreds of comments calling for an end to business in Russia), resulting in an Engagement Score of 100 (Figure 5). The lower score on Decathlon's profile was influenced by user posts (referring to the brand boycott), which lowered the average engagement per post. The engagement trends indicate that while Auchan experienced a sharp, temporary surge in early 2022, Decathlon Poland and Leroy Merlin Poland maintained steadier levels of consumer engagement.

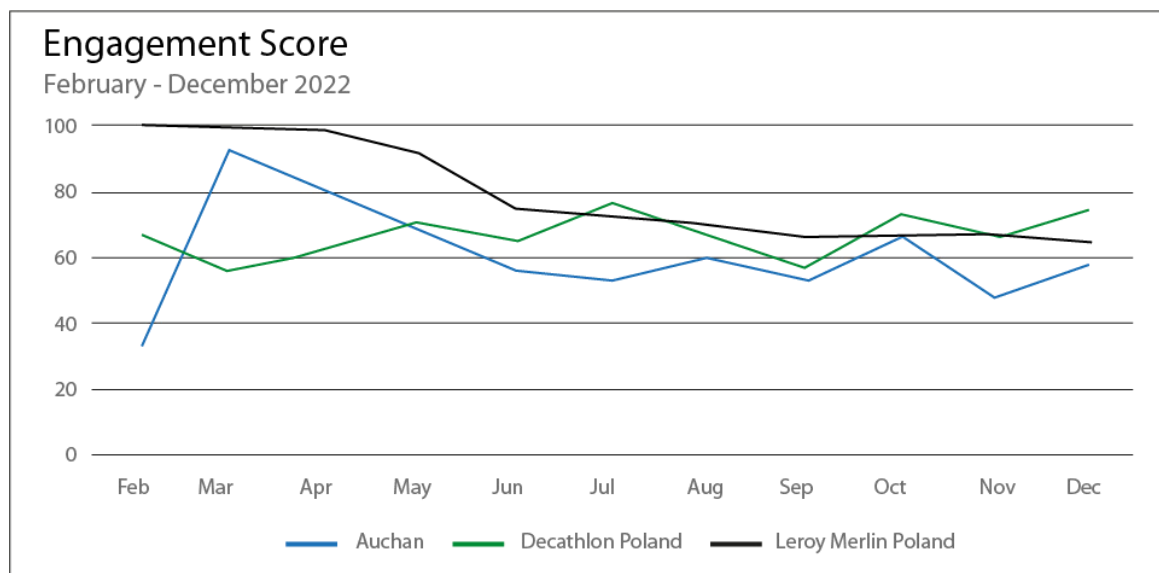


Figure 5. Engagement Score divided by months.

Throughout February to December 2022, a significant surge in user interactions related to the boycotts—comprising reactions, comments, and shares—was observed. This led to notable variations in the Interactivity Score among the brands, with Leroy Merlin achieving the highest engagement, followed by Decathlon and Auchan (Figure 6). Leroy Merlin, in particular, stood

out with an Interactivity Score peaking at 79, indicating its posts elicited higher engagement than 79% of the analyzed Polish Facebook profiles. This heightened engagement was not merely a reflection of post volume but was significantly influenced by the nature of the public discourse—predominantly negative comments stemming from the boycott calls. The heightened engagement levels, despite relatively fewer posts, were attributed to the public's boycott actions, particularly the extensive negative commentary.

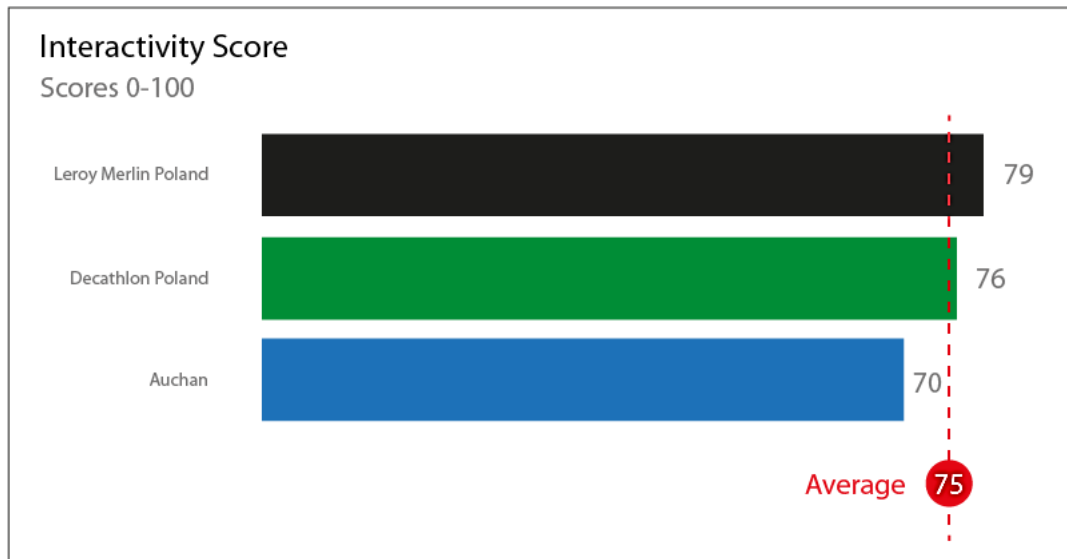


Figure 6. Interactivity Score.

Analysing the Interactivity Score trend over time, we can see that there was a significant volume of posts on Decathlon's profile as early as the end of February, just after the outbreak of the war in Ukraine. Customers clearly started to communicate their dissatisfaction with the brand remaining on the Russian market and declared a boycott of purchases at Decathlon in favour of the competition. In contrast, high engagement on the profiles of Auchan and Leroy Merlin was only recorded in March, when the decision not to withdraw these brands from Russia was publicised. Comments also drew attention to the barcodes of goods from Russia and Belarus (Figure 7).

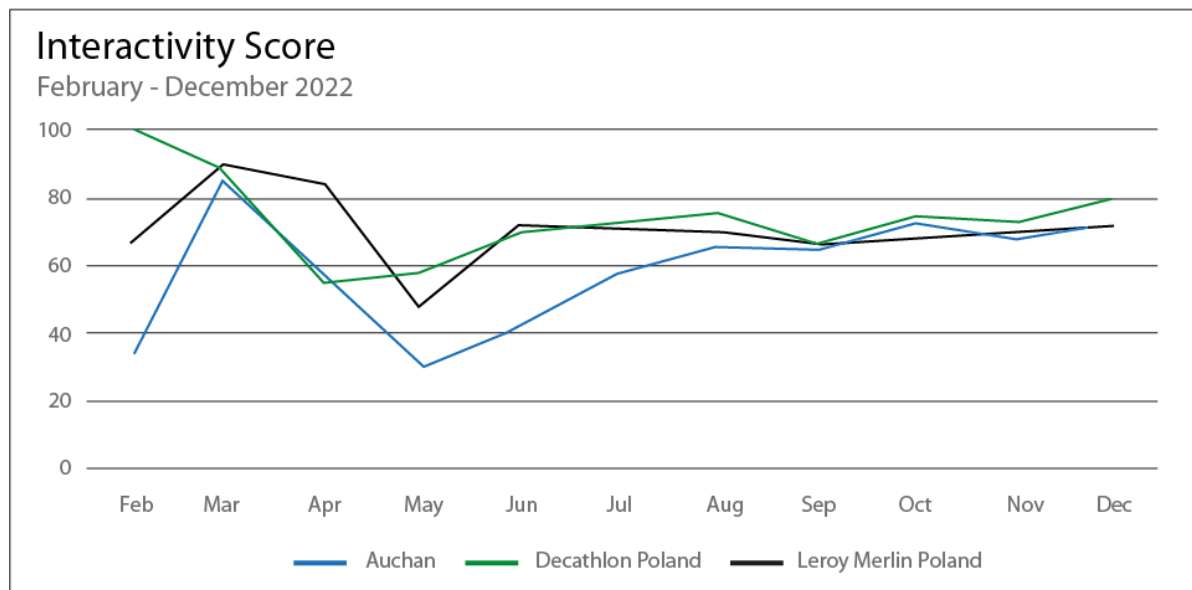


Figure 7. Interactivity Score divided by months.

In April, the Auchan and Decathlon brands decided to stop publishing posts, which resulted in a drop in engagement on these two profiles. Leroy Merlin, on the other hand, published 4 posts on its Facebook in April, all referring to Ukraine aid. However, the reception of the content was far from what was expected, with ANGRY and HAHA type reactions dominating under the posts and more than 60% of the comments having negative overtones. In May, content started to appear on Decathlon's profile again, which resulted in an increase in Interactivity Score. User comments ranged from those relating to the boycott of the Mulliez chain to those relating directly to product communication. There was still not a single post on the Auchan profile, while a post referring to Mother's Day appeared on the Leroy Merlin website, but was quickly removed due to the high number of negative comments. From June 2022, the situation changed and all profiles returned to regular posting. Comments calling for boycotts still appeared, but their number steadily decreased, Interactivity Score began to stabilise.

4.1. Content analysis

Between February 24th and December 31st, 2022, there were nearly 342,000 mentions (including posts and comments) of the brands Auchan, Decathlon, and Leroy Merlin on Facebook. These mentions underwent a detailed content analysis, which identified three main discussion themes:

1. Topics related to the war, including the suspension of business operations in Russia and consumer-driven activism.
2. Product-related content, focusing on store operations and offerings in Poland.
3. Mentions concerning product availability, promotions, and events sponsored by the brands.

For both Auchan and Leroy Merlin Polska, war-related content accounted for 32% of the total mentions, while the remaining 68% comprised various other topics (Figure 8). In contrast, Decathlon Polska had a significantly smaller share of war-related content at 15%, with the majority (85%) focused on non-war topics. Auchan had the highest total volume of content, with 49,084 war-related mentions and 105,028 other mentions. Overall, the data suggests that while all three brands experienced discussions linked to the war, Decathlon Polska had relatively less war-focused content compared to the other two brands.

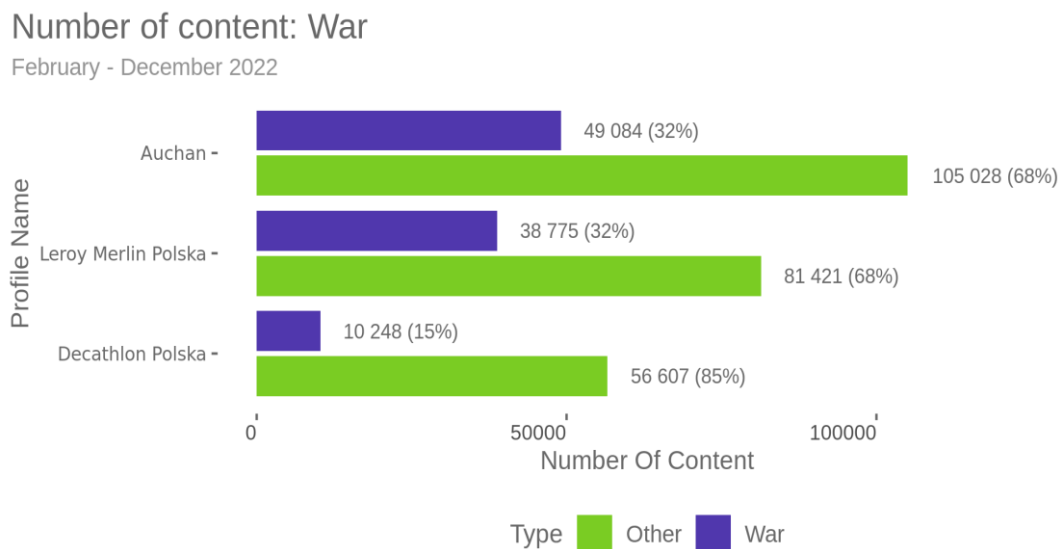


Figure 8. Number of war-related content.

The war-related data were further broken down into three specific categories: Boycott, Exit from Russia, and Other content (Figure 9). For Auchan, mentions related to boycotts made up 45% of the total war-related content, slightly surpassing discussions about their decision not to leave the Russian market (44%). This pattern might be linked to the competitive dynamics in the Polish market, where Decathlon faces limited competition, Leroy Merlin has a moderate level of competition, and Auchan is appealing to more price-sensitive consumers. Additionally, there was significant skepticism regarding the brands' strategies, with fewer demands for their withdrawal from Russia. This response may be attributed to the fact that none of the brands are Polish or have significant Polish ownership, potentially shaping the tone of public criticism.

The bar chart shows that Auchan had the highest volume of content across all three categories, with a notable portion allocated to boycott-related discussions. Leroy Merlin's content was balanced between boycott mentions (21%) and criticisms regarding their continued operations in Russia (53%). Decathlon, however, had a significant share of content focused on other issues (39%), indicating less emphasis on activism-related topics compared to the other two brands. This distribution highlights varying levels of public pressure and criticism faced by each brand during the analyzed period.

Number of content in each context

February - December 2022

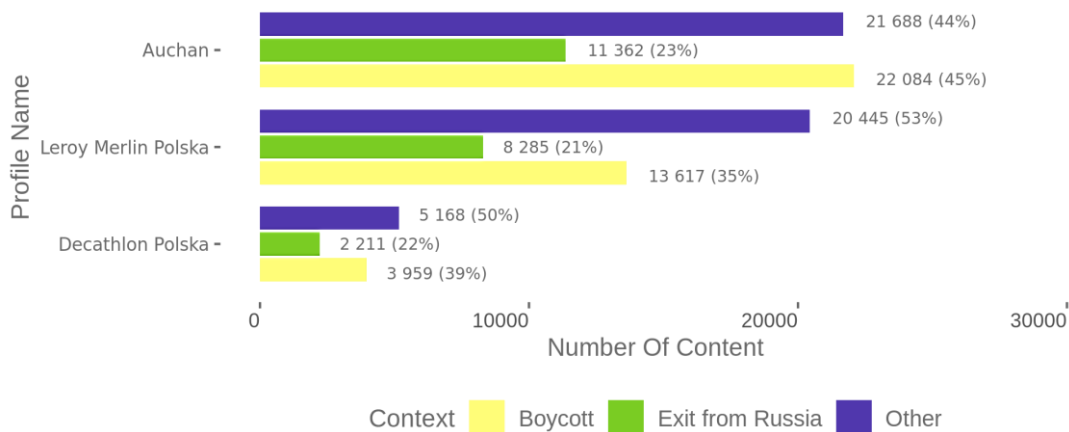


Figure 9. Number of content related to Boycott, Exit from Russia, Other.

Activism-related content, including calls for boycotts and criticism of the brands' choices to continue operations in the Russian market, attracted significant levels of user engagement (Figure 10). Although this type of content accounted for a smaller fraction of the total posts (notably for Decathlon), it still generated a high volume of interactions, highlighting the substantial role that social and geopolitical issues play in driving user activity.

Boycott-related discussions for Leroy Merlin Polska and Decathlon Polska, in particular, received strong user responses, signaling heightened public sentiment and critical engagement. This high level of interaction, especially for Leroy Merlin, appears to be influenced by consumer perceptions of the brand's strategic decisions within a sensitive geopolitical context. Overall, the data indicate that consumer activism had a pronounced effect on engagement patterns, with topics related to activism contributing significantly to the overall user interactions, despite their smaller share of the content. This finding suggests that, while general brand-related posts continued to be important, discussions driven by consumer activism had a considerable influence on shaping the broader public discourse surrounding these brands.

Engagement in each context: Interactivity Index

February - December 2022

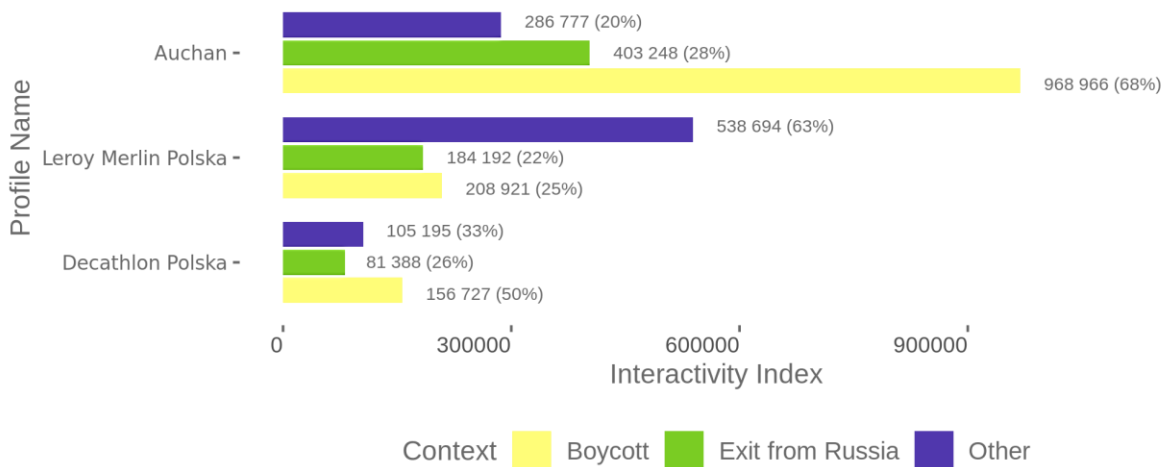


Figure 10. Engagement related to Boycott, Exit from Russia and Other content.

5. Discussion

This study provides insights into the dynamics of consumer engagement and sentiment on social media in the context of geopolitical conflict, specifically examining the response to the Mulliez Group's continued operations in Russia during the Russian-Ukrainian conflict. Our findings reveal a clear pattern in consumer behavior, characterized by an initial surge in engagement and a predominance of negative sentiment, particularly during the early stages of the conflict in March 2022. This heightened activity underscores the capacity of social media to rapidly mobilize consumer activism and drive widespread participation in boycotts, leveraging the platform's reach and immediacy to amplify consumer voices.

However, as the analysis indicates, this intense initial engagement is often short-lived. Despite the strong response observed immediately following Russia's aggression against Ukraine, the level of consumer activism and negative sentiment gradually subsided within a few months. The decline in engagement aligns with the concept of hedonic adaptation, where individuals initially exhibit strong emotional responses to significant events but gradually return to a baseline level of emotional intensity (Brickman, Campbell, 1971; Frederick, Loewenstein, 1999). This pattern suggests that while social media can be effective in mobilizing rapid, short-term activism, sustaining such movements over a prolonged period may be challenging due to shifts in public attention and emotional adaptation.

The stabilization of sentiment observed towards the end of the year further highlights the transient nature of public discontent. Although the conflict persisted, the intensity of negative consumer sentiment waned, pointing to the importance of strategic brand responses in managing the long-term impact of social media activism.

5.1. Implications for brand communication strategies

As consumer activism becomes more prominent on social media, companies face increasing pressure to manage these movements effectively, particularly in times of crisis. The rise of social media activism necessitates that brands develop comprehensive crisis communication strategies that include prompt acknowledgment of consumer concerns and transparent responses (Chavis, Leslie, 2009). Successful crisis management often involves directly engaging with stakeholders and addressing issues openly to rebuild trust (Pöyry, Laaksonen, 2022). However, a lack of response or inadequate handling of consumer grievances can exacerbate negative sentiment and lead to long-term damage to the brand's reputation (Koku, 2012).

The implications of this research emphasize the necessity for well-crafted brand communication strategies, particularly in responding to consumer activism on social media during socio-political crises. The backlash faced by the Mulliez Group for continuing operations in Russia illustrates the power of digital activism in shaping brand perception. Effective strategies, therefore, involve comprehensive crisis management practices that include real-time sentiment monitoring, active stakeholder engagement, and a dynamic approach to communication.

One of the critical elements in crisis communication is the use of transparent messaging. As seen in the case of Leroy Merlin, the absence of clear communication initially heightened the negative sentiment. Image Restoration Theory (IRT) offers a useful framework for addressing such crises, emphasizing strategies like corrective actions, partial apologies, and expressions of accountability (Benoit, 1997). These approaches are designed to convey sincerity and demonstrate the brand's commitment to addressing the underlying issues, which can be instrumental in rebuilding consumer trust.

Incorporating accommodative strategies, as outlined in the Contingency Theory of Accommodation (CTA), may provide an effective pathway for brands dealing with crises. The use of apologies, compensation, and expressions of sympathy can help de-escalate negative sentiment and enhance brand reputation (Coombs, 2015). Decathlon's adaptive approach, shifting its focus to community aid and engagement, highlights how accommodative responses can temper initial backlash and foster a more positive public dialogue. This adaptive strategy aligns with the need for brands to remain flexible, responding to changing consumer expectations and sentiment in real time.

Monitoring engagement metrics, such as Interactivity and Engagement Scores, offers a data-driven method to assess the effectiveness of communication strategies. High engagement levels, especially when driven by activism-related content, underscore the importance of actively participating in ongoing discussions rather than remaining silent. A "no comment" approach, as noted by Ulrich & Flöter (2014), is often interpreted as an admission of guilt and can exacerbate the crisis. Engaging directly with the conversation and acknowledging consumer concerns can help mitigate backlash and maintain a positive brand presence. This aligns with the recommendations from the Contingency Theory, which suggests balancing advocacy and accommodation to effectively navigate crisis situations (Cancel et al., 1997).

The choice of communication platform also plays a significant role in shaping brand messaging during a crisis. Schultz et al. (2011) argue that the medium of communication can be as important as the message itself, given the varying preferences of different consumer segments across platforms. For example, younger audiences may prefer immediate updates on platforms, while more detailed and community-oriented discussions may be better suited for Facebook. Tailoring the communication strategy to fit the platform's unique characteristics enhances the reach and impact of the brand's message, ensuring that it resonates with the target audience.

An evolutionary and adaptive approach to brand communication, as highlighted by Coombs (2015) and Do & Nham (2021), can be particularly effective in managing the fluid nature of social media activism. The findings show a transition from initial outrage to a more balanced sentiment over time, suggesting that brands benefit from an adaptive strategy that evolves with the changing dynamics of public discourse. By actively listening to consumer feedback and adjusting their messaging accordingly, brands can better navigate the complexities of digital activism, reducing the risk of prolonged reputational damage.

Moreover, the use of accommodative tactics, such as apologies and corrective actions, can be enhanced by incorporating elements of Image Restoration Theory (IRT) and Contingency Theory. For example, expressing sympathy and offering compensation can help demonstrate the brand's commitment to consumer well-being, fostering a sense of empathy and understanding (Coombs, 2015; Scher, Darley, 1997). This approach not only addresses the immediate concerns of the consumer but also helps build a long-term positive relationship, positioning the brand as responsive and responsible.

In summary, the integration of proactive monitoring, accommodative strategies, and platform-specific communication methods forms the backbone of effective brand communication in the context of social media activism. Leveraging frameworks like IRT and CTA provides a structured approach for responding to crises, allowing brands to balance advocacy with accommodation while addressing consumer concerns transparently. By maintaining an active dialogue, adapting messaging based on consumer feedback, and employing a data-driven approach to engagement metrics, brands can effectively manage crises, mitigate reputational risks, and strengthen consumer trust.

References

1. Anderson, M., Toor, S., Rainie, L., Smith, A. (2018). *Activism in the social media age*. Pew Research Center, <http://www.pewinternet.org/2018/07/11/activism-in-the-social-media-age/>
2. Benoit, W.L. (1997). Image repair discourse and crisis communication. *Public Relations Review*, 23(2), 177-186, [https://doi.org/10.1016/S0363-8111\(97\)90023-0](https://doi.org/10.1016/S0363-8111(97)90023-0).
3. Boulianne, S. (2015). Social media use and participation: A meta-analysis of current research. *Inf. Commun. Soc.*, 18(5), 524-538.
4. Bozkurt, S., Gligor, D. M., Babin, B.J. (2021). The role of perceived firm social media interactivity in facilitating customer engagement behaviors. *European Journal of Marketing*, 55(4), 995-1022. <https://doi.org/10.1108/EJM-07-2019-0613>
5. Bronnenberg, B.J., Dubé, J.P. (2022). Comment on “Spilling the beans on political consumerism: Do social media boycotts and buycotts translate to real sales impact?”. *Marketing Science*, 42(1), 28-31.
6. Cancel, A.E., Mitrook, M.A., Cameron, G.T. (1999). Testing the contingency theory of accommodation in public relations. *Public Relations Review*, 25(2), 171-197. [https://doi.org/10.1016/S0363-8111\(99\)80161-1](https://doi.org/10.1016/S0363-8111(99)80161-1)
7. Chavis, L., Leslie, P. (2009). Consumer boycotts: The impact of the Iraq war on French wine sales in the U.S. *Quantitative Marketing and Economics*, 7(1), 37-67. <https://doi.org/10.1007/s11129-008-9043-y>
8. Coombs, W.T. (2015). *Ongoing crisis communication: Planning, managing, and responding*. Los Angeles, CA: Sage.
9. De Zúñiga, H.G., Copeland, L., Bimber, B. (2014). Political consumerism: Civic engagement and the social media connection. *New Media Soc.*, 16(3), 488-506.
10. Do, B.N., Nham, T.P. (2021). Brand crisis response strategies: a typologies continuum. *Business: Theory and Practice*, 22(1), 146-158. <https://doi.org/10.3846/btp.2021.12586>.
11. Fredricks, J.A., Blumenfeld, P.C., Paris, A.H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research*, 74(1), 59-109. <https://doi.org/10.3102/00346543074001059>
12. Friedman, M. (1999). *Consumer Boycotts: Effecting Change Through the Marketplace and the Media*. Routledge.
13. Garrett, D.E. (1987). The effectiveness of marketing policy boycotts: Environmental opposition to marketing. *Journal of Marketing*, 51(2), 46-57. <https://doi.org/10.2307/1251128>
14. Grover, P., Kar, A.K, Dwivedi, Y. (2022). The evolution of social media influence-A literature review and research agenda. *Int. J. Inf. Manage. Data Insights*, 2(2).

15. Hartmann, T., Goldhoorn, C. (2011). Horton and Wohl revisited: Exploring viewers' experience of parasocial interaction. *Journal of Communication*, 61(6), 1104-1121. <https://doi.org/10.1111/j.1460-2466.2011.01595>.
16. Jae, M.K., Jeon, H.R. (2016). A study of ethnic perception gap on consumer boycott of Korean and Canadian University students. *Asia Pacific Journal of Innovation and Entrepreneurship*, 10(1), 55-66.
17. Jia, M., Zhao, Y., Song, S., Zhang, X., Wu, D., Li, J. (2024). How vicarious learning increases users' knowledge adoption in live streaming: The roles of parasocial interaction, social media affordances, and knowledge consensus. *Information Processing & Management*, 61(2), 103599. <https://doi.org/10.1016/j.ipm.2023.103599>
18. Johnson, O., Hall-Phillips, A., Chung, T.-L. (Doreen), Cho, H. (2019). Are You Connected Through Consumption? The Role of Hashtags in Political Consumption. *Social Media + Society*, 5(4).
19. Kaplan, A.M., Haenlein, M. (2012). Social media: Back to the roots and back to the future. *Journal of Systems and Information Technology*, 14(2), 101-104.
20. Kietzmann, J., Hermkens, K., McCarthy, I.P., Silvestre, B.S. (2011). Social Media? Get Serious! Understanding the Functional Building Blocks of Social Media. *Social Science Research Network*.
21. Kim, E.H., Yoo, D., Doh, S.J. (2021). Self-construal on brand fan pages: The mediating effect of para-social interaction and consumer engagement on brand loyalty. *Journal of Brand Management*, 28(3), 254-271. <https://doi.org/10.1057/s41262-020-00211-9>
22. Klein, J. (2003). The Boycott Puzzle: Consumer Motivations for Purchase Sacrifice. *Management Science*, 49(9), 1196-1209. <https://doi.org/10.1287/mnsc.49.9.1196.16569>
23. Klein, J., Smith, N.C., John, A. (2004). Why We Boycott: Consumer Motivations for Boycott Participation. *Journal of Marketing*, 68(3), 92-109. <https://doi.org/10.1509/jmkg.68.3.92.34770>
24. Koku, P.S., Akhigbe, A., Springer, T.M. (1997). The financial impact of boycotts and threats of boycotts. *Journal of Business Research*, 40(1), 15-20.
25. Kozinets, R. (2002). The Field Behind the Screen: Using Netnography for Marketing Research in Online Communities. *Journal of Marketing Research*, 39, 61-72.
26. Labrecque, L.I. (2014). Fostering Consumer–Brand Relationships in Social Media Environments: The Role of Parasocial Interaction. *Journal of Interactive Marketing*, 28(2), 134-148. <https://doi.org/10.1016/j.intmar.2013.12.003>
27. Lokhande, G., Natu, S. (2022). You are cancelled: Emergence of cancel culture in the digital age. *IAHRW International Journal of Social Sciences Review*, 10(2).
28. Ma, L., Ou, W., Lee, Ch.-S. (2022). Investigating consumers' cognitive, emotional, and behavioral engagement in social media brand pages: A natural language processing approach. *Electronic Commerce Research and Applications*, 54, 101179. <https://doi.org/10.1016/j.elerap.2022.101179>.

29. Pöyry, E., Laaksonen, S.M. (2022). Opposing brand activism: Triggers and strategies of consumers' anti-brand actions. *European Journal of Marketing*, 56(13), 261-284. <https://doi.org/10.1108/EJM-12-2020-0901>
30. Qian, Y., Xu, W., Liu, X., Ling, H., Jiang, Y., Chai, Y., Liu, Y. (2022). Popularity prediction for marketer-generated content: A text-guided attention neural network for multi-modal feature fusion. *Information Processing & Management*, 59(4), 102984. <https://doi.org/10.1016/j.ipm.2022.102984>
31. Ronzhyn, A., Cardenal, A.S., Batlle Rubio, A. (2023). Defining affordances in social media research: A literature review. *New Media & Society*, 25(11), 3165-3188. <https://doi.org/10.1177/14614448221135187>
32. Scher, S.J., Darley, J.M. (1997). How effective are the things people say to apologize? Effects of the realization of the apology speech act. *Journal of Psycholinguistic Research*, 26(1), 127-140. <https://doi.org/10.1023/A:1025068306386>
33. Schultz, F., Utz, S., Göritz, A. (2011). Is the medium the message? Perceptions of and reactions to crisis communication via twitter, blogs and traditional media. *Public Relations Review*, 37(1), 20-27. <https://doi.org/10.1016/>
34. Sen, S., Gürhan-Canli, Z., Morwitz, V. (2001). Withholding consumption: A social dilemma perspective on consumer boycotts. *Journal of Consumer Research*, 28(3), 399-417. <https://doi.org/10.1086/323729>
35. Smith, N.C., Cooper-Martin, E. (1997). Ethics and target marketing: The role of product harm and consumer vulnerability. *Journal of Marketing*, 61(3), 1-20. <https://doi.org/10.2307/1251786>
36. Sun, Q., Wu, F., Li, S., Grewal, R. (2021). Consumer boycotts, country of origin, and product competition: Evidence from China's Automobile Market. *Management Science*, 67(9), 5857-5877. <https://doi.org/10.1287/mnsc.2020.3778>
37. Uhrich, S., Flöter, T. (2014). Sponsor Response Strategies for Avoiding Negative Brand Image Effects in a Sponsorship Crisis: The Comparative Efficacy of Apology, Denial and No Comment. *Marketing: ZFP – Journal of Research and Management*, 36(4), 257-266. <http://www.jstor.org/stable/26426740>
38. Yuksel, U., Mryteza, V. (2009). An Evaluation of Strategic Responses to Consumer Boycotts. *Journal of Business Research*, 62, 248-259.
39. Zeng, P.F., Wang, R., Li, A.P.S.Y., Qu, A.P.Z. (2022). Social Media Advertising through Private Messages and Public Feeds: A Congruency Effect between Communication Channels and Advertising Appeals. *Information & Management*, 59(4), 103646. <https://doi.org/10.1016/j.im.2022.103646>
40. Zhang, S., Zhang, Y., Li, J., Ni, Z., Liu, Z. (2024). Heart or mind? The impact of congruence on the persuasiveness of cognitive versus affective appeals in debunking messages on social media during public health crises. *Computers in Human Behavior*, 154, 108-136. <https://doi.org/10.1016/j.chb.2024.108136>

METHODOLOGY FOR ASSESSING EMPLOYEE PREDISPOSITIONS TO TYPES OF JOBS IN ORDER TO REDUCE TURNOVER IN MANUFACTURING ENTERPRISES

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Purpose: The article presents an original methodology for assessing employee predispositions to three types of work: manual, manual-machine, and automatic. The aim of the methodology is to reduce employee turnover and improve retention in manufacturing companies.

Design/methodology/approach: The study was conducted on a group of 31 newly employed people in a manufacturing plant in Poland, of whom 11 employees resigned within the first 30 days of employment. The results of the predisposition assessment were analyzed to identify the factors that influence an employee to quit.

Findings: The conclusions indicate that employees with lower predisposition assessment results were more likely to leave the company, while higher results were correlated with greater retention. The original methodology for assessing predispositions, including various aspects of manual, sensory, and logical-analytical work, aims to better match employees to appropriate positions.

Practical implications: The proposed methodology can be applied by HR and production managers to improve hiring and retention in manufacturing. By assessing employee predispositions early on, companies can match individuals to roles better suited to their skills, potentially leading to higher job satisfaction, lower turnover, and reduced recruitment costs. This approach also aids in identifying employees more likely to succeed in specific environments, facilitating better workforce planning.

Originality/value: This unique methodology contributes to improving job satisfaction and reducing turnover costs by aligning employee predispositions with suitable job roles in manufacturing environments.

Keywords: Employee predisposition assessment, Employee retention, Employee turnover.

Category of the paper: Research paper.

1. Introduction

One of the key challenges facing modern manufacturing companies is the effective allocation of employees to appropriate job positions (Bailey, De Propriis, 2014; Certa et al., 2009; Martínez-Mora, Merino, 2014; Pal et al., 2014). Studies show that the subjective beliefs of supervisors often lead to discrimination based on gender, age, and physical predispositions, which makes it difficult to objectively allocate employees to appropriate roles (Hamadamin, Atan, 2019). Such stereotypes are common in work environments and can lead to unequal opportunities for certain groups of employees, even though actual competences are not related to these characteristics (Goldenhar et al., 1998; Murrell et al., 1999). Stereotypes about the abilities of women and men to perform manual and physically demanding tasks have been repeatedly debunked in literature (Bayer, 1990; Salah et al., 2023; Schmader et al., 2008; Spencer, 1999; Zemore et al., 2000).

As Peters and Campagnaro (1996) point out, one myth is the belief that manual work requiring precision, such as the finishing of products, is more suitable for women. However, their research shows that there are no statistically significant differences in the manual skills of men and women while taking into account similar physiological characteristics, such as hand size and grip strength. Similarly, the myth that men are better at operating heavy machinery, such as presses, has been dispelled by research. Studies conducted by Cox and Harquail (2009) in manufacturing plants shows that women can achieve some of the best results in this field, indicating that technical skills and training are more important than physical strength, especially if organizations invest in solutions that optimize work.

Research shows that companies need to rely much more on HR data when making hiring decisions. This is because intuitive or stereotypical approaches contribute to increased employee turnover (Gaikwad et al., 2023; Alshammari et al., 2016). Employee turnover generates high costs related to the recruitment and training of new employees, which negatively impacts operational continuity and employee morale (Alshammari et al., 2016). These costs can amount to 50% to 60% of an employee's annual salary, and their impact extends beyond financial issues – including the weakening of organizational culture and the reduction of team effectiveness (WebHR, 2024; TalentUp, 2023). Incorrect assumptions based on intuition or stereotypes lead to employees being assigned to tasks that do not match their actual skills. This approach results in reduced productivity, decreased job satisfaction, and increased employee turnover (Gaikwad et al., 2023; Moon et al., 2022).

Research conducted by Osborne and Hammoud (2017) indicates that high employee turnover significantly destabilizes team dynamics, which in turn leads to lower morale and lower operational efficiency. Employees who see frequent changes in their team may feel both a lack of stability and certainty about the future of their role, which results in lower engagement and a greater propensity to leave the company. This phenomenon is especially visible when

team relationships and the level of trust between employees are disrupted by constant turnover (Wang, Sun, 2023). High turnover can also increase the costs associated with recruiting and training new employees, and cause the loss of key institutional knowledge, which further weakens organizational performance (Yücel, 2021).

To counteract these negative effects, companies should implement talent management strategies, such as investing in employee development, creating a positive work culture, and offering career development opportunities (Boxall, Macky, 2009; Hom et al., 2017). Research suggests that such actions can not only reduce turnover rates, but also improve overall organizational performance, leading to long-term operational success (MDPI, 2021; Workplace Incivility Review, 2023).

The methodology presented in the article for assessing employee predispositions to work is intended to help organizations direct employees to the types of jobs that are most suitable for them, without relying on parameters such as gender, age, or appearance. Such actions are intended to increase job satisfaction in people who are currently employed, which in turn has an influence on greater retention. The methodology has been verified in industry, and this publication presents the conclusions drawn from it.

2. The author's own research conducted in industry

The author's own research, which was conducted in the manufacturing industry at an automotive company, showed that as many as 38.23% of new employees hired in the production area resign from work within the first month. This research was conducted at a plant in Poland on a sample of 863 employees employed in the period between 2021 and 2022. As part of the research, it was verified how many employees resigned from work within the first 30 days of being hired. Out of the group of 863 employees, 330 employees resigned from work in the first 30 days. Figure 1 shows, based on surveys and exit interviews, what the reasons were for these 330 employees leaving.

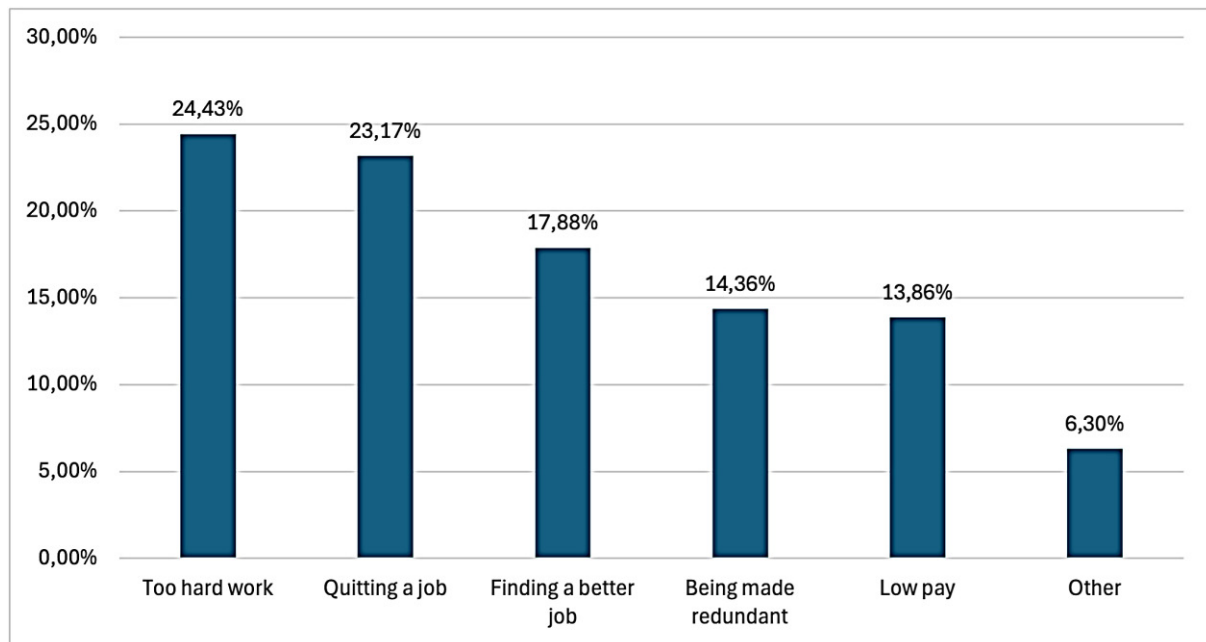


Figure 1. Reasons for employees leaving work.

Source: Authors' own creation.

Reasons such as too much work, quitting the job, or being made redundant by an employer can be associated with the fact that the employee was not properly assigned to the job position, and therefore did not feel satisfied with his job. This research resulted in the development of a methodology that allows for the assessment of employees' predispositions to work in order to direct them to their optimal positions. This paper presents the results of research that was conducted in 2023 after the application of the methodology for assessing predispositions.

High employee turnover is associated with huge costs for organizations, not only financial but also organizational. This is due to the fact that each new recruitment requires the re-training, preparation and onboarding of employees (Kumar et al., 2023). Reports such as the Deloitte Manufacturing Perception Study (2022) show that nearly 83% of manufacturing companies struggle with the problem of attracting and retaining a skilled workforce. These problems result from changing employee expectations and the increase of the competition for talent, both in local and global markets (Hoffman et al., 2020). The lack of appropriate tools for assessing employee predispositions and the shortages of skilled labour lead to costly recruitment processes and reduced engagement, which additionally increases employee turnover (Deloitte, 2022).

3. Types of work in production processes

In research on production processes, three main types of work can be distinguished (Graupp and Wrona, 2016):

- Manual.
- Manual - machine.
- Automatic.

A description of these types of work and their explanation are presented in Table 1. Each of these types of work is crucial for the proper functioning of production and understanding them helps in the appropriate allocation of human resources.

Table 1.

Explanation of the types of work performed by employees in production processes

Type of work	Explanation	Required skills
Manual work	Traditionally associated with tasks requiring precision and dexterity, such as the assembly of small parts or quality control. Manual work is still important in many sectors, especially where flexibility in production, tailored to customer needs, is required.	- Manual dexterity. - Eye-hand coordination. - Perseverance and concentration.
Manual and machine work	Combine manual activities with machine operation. Employees in these types of tasks cooperate with machines - making adjustments or monitoring production processes.	- Sensory skills. - Basic technical knowledge. - Ability to respond to emergencies.
Automatic work	Refers to the supervision of fully automated production lines. Workers in these roles must monitor advanced systems and troubleshoot problems that may arise during the operation of machines. Automation does not eliminate the need for human involvement, especially in the case of more complex tasks that require data analysis or decision-making.	- Logical and analytical skills. - Problem-solving skills. - Knowledge of digital technologies.

Source: Authors' own creation based on: Cohen, Apte, 1997; Graupp, Wrona, 2016; Gustafson, 2013; Kawashimo et al., 2009; Lordan, Josten, 2020; Noor et al., 2021; Rashid, Rötting, 2021.

As part of the developed methodology, tasks were prepared to verify the predispositions of employees to these 3 types of work by checking their skills that are characteristic for a given type of work. Each of these three types of work requires specific skills - from manual and sensory dexterity to analytical and technical skills in automatic work.

4. Methodology for assessing employee predispositions

The methodology for assessing employee predispositions was created to reliably assess employee predispositions and support supervisors in the decision-making process of assigning new employees to specific work positions. This assessment will provide data that will help employers make better decisions about assigning employees to production positions. This will shorten the employee's introduction time to the position, will result in a faster achievement of the required efficiency and quality of work, and will increase team morale, in turn reducing employee turnover. As part of the methodology, eight tasks were prepared, which were matched to three types of work using the weight system (Table 2).

Table 2.

Areas of assessment of employee predispositions

Area		Assigned weight for work type		
		Manual work	Manual and machine work	Automatic work
1	Precision of work performed using tools	5	2	1
2	Precision of work performed using hands	5	2	1
3	Manual precision	5	1	1
4	Observation skills	3	5	4
5	Ability to read instructions	2	5	4
6	Memorizing sequences	2	5	4
7	Logical thinking test	1	3	5
8	Test of problem-solving and analysis skills	2	2	5
Total		25	25	25

Source: Authors' own creation.

It was assumed that precision tasks are associated with manual work, and tasks related to perception or sensory skills are related to manual-machine work. Logical thinking or the ability to solve problems are given the highest importance for automatic work. It was assumed that all the skills are necessary in each type of work, but not necessarily at the same level, hence the weight system being introduced. The methodology for assessing employee predispositions allows for assessing to which type of work a given employee is best suited for. This assessment recommends the type of work. However, it is worth remembering that an employee may always experience stress during the assessment, which may affect the results. Therefore, in addition to measurements, employee behavior should also be observed, which may help assess their predispositions.

4.1. Time and quality parameters adopted in the methodology

Time and quality parameters are key elements in assessing employee performance (Bryan, Locke, 1967; Zakay, Wooller, 1984). The time parameter refers to the speed of task completion, which helps in assessing work organization, efficiency, and an employee's ability to work under

pressure. In turn, the quality parameter measures how well a task is completed in accordance with quality requirements. This affects the final work result and the organization's productivity. Kerstholt (1994) emphasizes that time pressure can force employees to shorten procedures, which reduces the quality of work. However, properly managed time pressure can increase efficiency without negatively affecting quality, as suggested by Moore and Tenney (2012). Deci et al. (2017) indicate that monitoring both parameters results in better productivity management, higher levels of employee engagement, and better operational results. In the context of manufacturing, Cintrón and Flaniken (2011) suggest that explicit performance evaluation mechanisms that take into account both time and quality help organizations achieve better results. In the research of Na-Nan et al. (2018), it was shown that monitoring time and quality parameters is particularly important in industries such as automotive assembly, where precision and speed are crucial for operational success.

Therefore, when assessing tasks in the proposed methodology, two main aspects were adopted for assessment: the time parameter and the quality parameter. The time parameter determines how quickly an employee is able to perform a given task, which in turn allows for their work organization and efficiency to be assessed. The quality parameter measures the accuracy, correctness and compliance of the performed task with the requirements. Table 3 contains a detailed description of these parameters for each task.

Table 3.

Detailed description of parameters for the prepared tasks, which check work predispositions

Task	Description of the performed task	Time parameter	Quality parameter
Test for precision of work using tools	The employee is required to cut out the two letters 'C' and 'S' in different sizes using scissors.	Time measured from the moment the cutting starts until it is finished. Too long a time may suggest a lack of skill in using tools.	Quality assessment based on the precision of the letter cutting. Product rated as 0 (poor workmanship) or 1 (good workmanship). Attention is paid to the lack of jaggedness and the correct shape.
Test for precision of work using hands	The employee must pull a thread through the eye of a needle and cut it to a specified length.	Time is measured from the moment the thread is touched to the moment it is pulled through the eye of the needle. A shorter time indicates better mastery of the task.	Quality assessment based on the correctness of the thread length measurement. Deviations from the standard (+/- 0.5 cm) reduce the quality assessment.
Test for manual precision	The employee draws patterns without lifting the pen from the paper.	Time is measured for each pattern separately.	Quality assessed by the number of errors – e.g. lifting the pen or leaving a dot.
Test for observation skills	The employee's task is to find the differences between two pictures and label numbers.	Time is measured for each picture and sequence of numbers. A longer time may suggest decreased perceptiveness.	Quality assessment based on the number of correctly found differences and numbers.
Test for the ability to read instructions	Based on instructions, an employee needs to fold two paper airplanes.	Time is measured from the moment the instructions are downloaded to the completion of the airplane.	Quality assessment based on compliance of the made airplane to the pattern in the instructions.

Cont. table 3.

Test for memorizing sequences	The employee has to memorize sequences of shapes, colours and numbers and then reproduce them.	Time is measured for each sequence separately. A shorter time indicates a better working memory.	Quality assessment based on the number of correctly reproduced elements.
Logical test	The employee has to answer logical questions within a specified time.	The time to solve the task is 9 minutes. This time is enough to complete the task and answer correctly.	Quality rating is based on the number of correct answers and errors. Incorrect answers reduce the score.
Test for problem-solving	The employee is meant to answer questions regarding problematic situations in the production process.	Time is measured from the start of the test to its completion. A shorter time means faster problem resolution.	Quality assessment based on the accuracy and completeness of responses. Errors in the analysis lower the score.

Source: Authors' own creation.

In each group of tasks, a maximum of 10 points can be obtained. In the case of failure to meet the quality criterion, the assessment is from 1 to 5 points, and in the case of meeting the quality criterion, the assessment is from 6 to 10 points. The assessment in a given range is influenced by the result related to the time parameter.

4.2. Determining the quality and time parameters for an exemplary task

In order to present how the quality and time parameters for a task are determined, exemplary task number 1 was used: a test for the precision of work using tools. In the case of the qualitative assessment, the guidelines presented in Table 4 were followed, according to which it was recognized whether a given element that was cut out met the quality criterion.

Table 4.

Qualitative evaluation of cutting out elements using scissors

Qualitative assessment	Description of the assessment guidelines
No quality maintained – a maximum score from 1 to 5 points based on completion time	When there are more than 3 white elements of the page outside the outline or there are ragged edges. In the example, there are 4 white elements protruding outside the outline and there are also ragged edges. 
Quality maintained – a maximum score of 6 to 10 points based on the completion time	When there are less than 3 white elements outside the outline and there are no jags or cuts inside the letter. In the example, there is only one white element outside the outline. 

Source: Authors' own creation.

Perceived performance times should be measured based on the skills of the best employees. Table 5 shows the measured performance times for a group of experienced operators.

Table 5.

Scoring for task number 1 - a test for the precision of work using tools - which allows the execution of cutting a given letter with scissors with regards to the cutting time and fulfillment of the quality criterion to be assessed

Scoring basing on time in minutes	1	2	3	4	5	6	7	8	9	10
	A lack of quality					Quality is maintained				
Capital letter „C”	01:21 – >	01:01 – 01:20	00:51 – 01:00	00:41 – 00:50	00:01 – 00:40	01:21 – >	01:01 – 01:20	00:51 – 01:00	00:41 – 00:50	00:01 – 00:40
Capital letter „S”	01:21 – >	01:01 – 01:20	00:51 – 01:00	00:41 – 00:50	00:01 – 00:40	01:21 – >	01:01 – 01:20	00:51 – 01:00	00:41 – 00:50	00:01 – 00:40
Small „C”	01:16 – >	00:56 – 01:15	00:46 – 00:50	00:36 – 00:45	00:01 – 00:35	01:16 – >	00:56 – 01:15	00:46 – 00:50	00:36 – 00:45	00:01 – 00:35
Small „S”	01:16 – >	00:56 – 01:15	00:46 – 00:50	00:36 – 00:45	00:01 – 00:35	01:16 – >	00:56 – 01:15	00:46 – 00:50	00:36 – 00:45	00:01 – 00:35

Source: Authors' own creation.

The maximum score of 10 points means that the employee performed the task correctly, qualitatively, and in a time that was between 1 second and 40 seconds for the capital letters and between 1 second and 35 seconds for the small letters. The final score for a given group of tasks is the average of the scores from four assessments for different sizes of letters.

4.3. Interpretation of the obtained results in the methodology

After conducting the tests to assess the predispositions of employees as part of the job predisposition assessment methodology, results were obtained for three types of work: manual, manual-machine and automatic. Each test is assessed based on previously established criteria, including time and quality parameters. In total, for each type of work, the employee can receive a maximum of 250 points. This value is the result of multiplying the sum of the weights described in Table II, which for each type of work is 25, with a maximum value of 10 points for each group of tasks.

Each task was calibrated to a maximum point value based on the specific requirements for the type of work, which in turn ensures the reliability of the assessment. Table 6 presents the interpretation of the obtained results for each type of work.

Table 6.

Interpretation of the results for each type of work

Result for a given type of work	Interpretation of the obtained result
230-250 points	Outstanding predispositions for a given type of work
210-229 points	Very good predispositions for a given type of work
180-209 points	Good predispositions for a given type of work
160-179 points	Average predispositions for a given type of work
130-159 points	Weak predispositions for a given type of work
25-130 points	Very poor predispositions for a given type of work

Source: Authors' own creation.

Point values allow for the identification of the group of work types to which an employee has the greatest predispositions. It is possible that the results of employees will be similar in the case of different job types. In such a situation, it means that the employee has equal predispositions to several types of tasks, which gives the supervisor more flexibility in the decision-making process. In turn, a low score in all work types may be, among other things, the result of stress during the test. It is recommended to conduct a conversation with the employee in such situations to understand the reasons for the results, and if necessary, repeat the assessment in more favorable conditions.

5. Application of the methodology for assessing predispositions in industry

Research concerning the application of the predisposition assessment methodology in industry were conducted on a group of 31 newly hired employees in a factory in Poland. The research provided interesting results that allow for a better understanding of the mechanisms that influence the decision about resigning from work. From the study group, 11 employees resigned within the first 30 days of employment, which constituted 35.48% of the study population. It is worth emphasizing that the predisposition assessment methodology was not used to make decisions on assigning employees to specific tasks. However, the test results were analyzed post factum to understand what factors could have influenced the employees to leave.

The predisposition tests concerned three types of work: manual, manual-machine and automatic. Each of these types of work required specific skills that were assessed in the predisposition tests. Based on the results of the employees, it was found that those who obtained higher test scores were more likely to stay in the company, while employees with lower scores were more likely to resign from work. The results are presented in Table 7.

Table 7.

The predisposition assessment test results achieved by 31 tested newly recruited employees

Results:	Manual work	Manual-machine work	Automatic work
The average result for the group of 31 people included in the study	169.55	142.39	129.03
The average result for the group of 11 people who quit their jobs in the first 30 days	120.45	105.18	104.63
The average result for the group of 20 people who stayed in their job for more than 30 days	196.55	162.85	142.45

Source: Authors' own creation.

In the case of manual work, those who left scored an average of 120.45 points, while those who stayed more than 30 days scored an average of 196.55 points. These results suggest that those who were less engaged in manual tasks were less willing to work from the very beginning,

and therefore approached the tasks with less energy and commitment. A similar trend was observed in the case of manual-machine work, where employees who left scored an average of 105.18 points, while those who stayed scored an average of 162.85 points. Significant differences in scores were observed in the case of predisposition to automatic work. The employees who stayed with the company scored an average of 142.45 points, while those who left scored only 104.63 points. An interesting observation was that two employees with outstanding predispositions to work on more advanced machines decided to leave, which suggests that the simpler, repetitive tasks assigned to them in production did not meet their expectations. These people scored 172 points and 157 points, respectively. These people confirmed in the „Exit Interview” that their leave was due to the too simple and repetitive tasks to which they were assigned.

The presented results show that people who were not sufficiently engaged in manual tasks scored lower in the predisposition tests. It is worth emphasizing that employees who achieved a low score in all the three types of work may have experienced stress during the tests, which could have affected their results. In such cases, it is recommended to conduct additional interviews to better understand the reasons for the low scores, and also their potential impact on the employee's decision to leave.

6. Conclusions

The conclusions drawn from the research concerning the application of the employee predisposition assessment methodology show that this tool can significantly contribute to improving retention and reducing turnover in manufacturing companies. The results obtained during the implementation of the methodology indicate that employees who are better suited to specific types of work are more likely to stay in the company, which in turn translates into better operational efficiency and lower costs related to recruiting and training new employees.

Analysis of the research results suggests that people who scored high on tests of predisposition for manual, manual-machine or automatic work showed higher levels of engagement and job satisfaction, which had a direct impact on their decision to continue employment. Employees who quit within the first 30 days of employment scored lower on the tests, which in turn suggests that a lack of a proper fit to the tasks may have been one of the key factors for their leaving.

The methodology of assessing employee predispositions enables the precise matching of employees to tasks, which leads to a better allocation of human resources in manufacturing organizations. These results confirm previous hypotheses that employee turnover can be significantly reduced thanks to a better assessment of predispositions at the stage of the recruitment and implementation of new employees. It is therefore concluded that the regular

use of this methodology can significantly affect the optimization of HR processes in manufacturing companies, in turn increasing both operational efficiency and employee satisfaction.

Further research in this area is recommended, especially in the context of the long-term impact of this methodology on employee career development, as well as its application in industries beyond the manufacturing industry. It is also recommended to test this solution and make decisions about whether to hire employees, and for which positions to recommend them. It would then also be necessary to analyze whether employee turnover is reduced. Research in this area will continue.

References

1. Alshammari, M.A., Al Qaied, B.A., Al-Mawali, H., Matalqa, M. (2016). What drives employee's involvement and turnover intentions: Empirical investigation of factors influencing employee involvement and turnover intentions. *International Review of Management and Marketing*, Vol. 6, No. 2, pp. 298-306.
2. Bailey, D., De Propriis, L. (2014). Reshoring: Opportunities and Limits for Manufacturing in the UK – the case of the Auto Sector. *Revue d'économie industrielle*, 145(1), pp. 45-61. DOI: 10.4000/rei.5732.
3. Beyer, S. (1999). Gender differences in the accuracy of self-evaluations of performance. *Journal of Personality and Social Psychology*, 77(3), pp. 519-531. DOI: 10.1037/0022-3514.77.3.519.
4. Boxall, P., Macky, K. (2009). Research and theory on high-performance work systems: Progressing the high-involvement stream. *Human Resource Management Journal*, Vol. 19, No. 1, pp. 3-23. DOI: 10.1111/j.1748-8583.2008.00082.
5. Bryan, J.F., Locke, E.A. (1967). Goal setting as a means of increasing motivation. *Journal of Applied Psychology*, 51(3), pp. 274-277. DOI: 10.1037/h0024566.
6. Certa, A., Enea, M., Galante, G. (2009). Multi-objective human resources allocation in R&D projects planning. *International Journal of Production Research*, Vol. 47 No. 13, pp. 3503-3523.
7. Cintrón, R., Flaniken, F. (2011). Performance Appraisal: A Supervision or Leadership Tool? *International Journal of Business and Social Science*, Vol. 2, No. 17, pp. 29-37.
8. Cohen, M.A., Apte, U.M. (1997). Manufacturing automation. *Production and Operations Management*, 6(2), pp. 108-126.
9. Cox, T., Harquail, C.V. (2009). The human side of change: Predictors of technical performance in job-related skills. *Journal of Organizational Behavior*, Vol. 30, No. 4, pp. 620-634.

10. Deci, E.L., Olafsen, A.H., Ryan, R.M. (2017). Self-determination theory in work organizations: The state of a science. *Annual Review of Organizational Psychology and Organizational Behavior*, Vol. 4, pp. 19-43.
11. Deloitte (2022). Competing for talent: Recasting perceptions of manufacturing. Deloitte Insights, available at: <https://www2.deloitte.com/us/en/insights/industry/manufacturing/competing-for-manufacturing-talent.html>, 8 October 2024.
12. Gaikwad, S.B., Ramya, S.T., Tiwari, T., Tiwari, M., Kumar, B. (2023). Predicting employee turnover: A systematic machine learning approach for resource conservation and workforce stability. *Eng. Proc.*, Vol. 59 No. 1, DOI: <https://doi.org/10.3390/engproc2023059117>.
13. Goldenhar, L.M., Swanson, N.G., Hurrell Jr, J.J., Ruder, A., Deddens, J., (1998). Stressors and adverse outcomes for female construction workers. *Journal of Occupational Health Psychology*, 3(1), pp. 19-32. DOI: 10.1037/1076-8998.3.1.19
14. Graupp, P., Wrona, R.J. (2016). *The TWI Workbook: Essential Skills for Supervisors*. Productivity Press.
15. Gustafson, A., Schunnesson, H., Galar, D., Kumar, U. (2013). Production and maintenance performance analysis: manual versus semi- automatic LHDs. *Journal of Quality in Maintenance Engineering*, Vol. 19, No. 1, pp. 22-35.
16. Hamadamin, H.H., Atan, T. (2019). The impact of strategic human resource management practices on competitive advantage sustainability: The mediation of human capital development and employee commitment. *Sustainability*, Vol. 11, No. 20, p. 5782, DOI: 10.3390/su11205782.
17. Hoffman, B.J., Shoss, M.K., Wegman, L.A. (2020). The Changing Nature of Work and Workers: An Introduction. In: B.J. Hoffman, M.K. Shoss, L.A. Wegman (eds.), *The Cambridge Handbook of the Changing Nature of Work*. Cambridge: Cambridge University Press, pp. 3-19. DOI: <https://doi.org/10.1017/9781108278034.001>.
18. Hom, P.W., Lee, T.W., Shaw, J.D., Hausknecht, J.P. (2017). One hundred years of employee turnover theory and research. *Journal of Applied Psychology*, Vol. 102, No. 3, pp. 530-545. DOI: 10.1037/apl0000103.
19. Kawashimo, T., Sato, N., Doyo, D., Anse, M., Tabe, T. (2009). A Skill Transfer Method for Manual Machine Tool Operation Utilizing Cutting Sound. *Human Interface and the Management of Information. Designing Information Environments (Human Interface 2009), Lecture Notes in Computer Science*, Vol. 5617, Springer, pp. 77-86.
20. Kerstholt, J.H. (1994). The effect of time pressure on decision-making behaviour in a dynamic task environment. *Acta Psychologica*, Vol. 86, No. 1, pp. 89-104. DOI: [https://doi.org/10.1016/0001-6918\(94\)90013-2](https://doi.org/10.1016/0001-6918(94)90013-2).
21. Kumar, P., Gaikwad, S.B., Ramya, S.T., Tiwari, T., Tiwari, M., Kumar, B. (2023). Predicting Employee Turnover: A Systematic Machine Learning Approach for Resource Conservation and Workforce Stability. *Eng. Proc.*, 59(1), p. 117. DOI: <https://doi.org/10.3390/engproc2023059117>.

22. Lordan, G., Josten, C. (2020). Automation and the changing nature of work. *PLOS ONE*. DOI: 10.1371/journal.pone.0235815
23. Martínez-Mora, C., Merino, F. (2014). Offshoring in the Spanish footwear industry: A return journey? *Journal of Purchasing and Supply Management*, 20(4), pp. 225-237. DOI: 10.1016/j.pursup.2014.07.001.
24. MDPI (2021). *Workplace incivility and turnover intention in organizations: A meta-analytic review*, available at: <https://www.mdpi.com>, 8 October 2024.
25. Moon, K., Loyalka, P., Bergemann, P., Cohen, J. (2022). The hidden cost of worker turnover: Attributing product reliability to the turnover of factory workers. *Management Science*, available at: <https://pubsonline.informs.org/doi/10.1287/mnsc.2021.4079>, 8 October 2024.
26. Moore, D.A., Tenney, E.R. (2012). Time pressure, performance, and productivity. *Research on Managing Groups and Teams*, Vol. 15, pp. 305-326.
27. Murrell, A.J., Crosby, F.J., Ely, R.J. (eds.) (1999). *Mentoring Dilemmas: Developmental Relationships Within Multicultural Organizations*. Mahwah, NJ: Psychology Press.
28. Na-Nan, K., Chaiprasit, K., Pukkeeree, P. (2018). Factor analysis-validated comprehensive employee job performance scale. *International Journal of Quality & Reliability Management*, Vol. 35, No. 10, pp. 2436-2449. DOI: <https://doi.org/10.1108/IJQRM-06-2017-0117>.
29. Noor, H.A.M., Bin Ramli, M.N.S., Kassim, R., Rahman, F.A., Baharum, Z., Salleh, F.I.M. (2021). The Effectiveness of Automated Machine Over Manual Machine in Operational Line. *International Journal of Online & Biomedical Engineering*, Vol. 17 No. 12, p. 19, DOI: 10.3991/ijoe.v17i12.24729.
30. Osborne, S., Hammoud, M.S. (2017). Effective employee engagement in the workplace. *International Journal of Applied Management and Technology*, 16(1), pp. 50-67.
31. Pal, R., Torstensson, H., Mattila, H. (2014). Antecedents of organizational resilience in economic crises—an empirical study of Swedish textile and clothing SMEs. *International Journal of Production Economics*, 147(B), pp. 410-428. DOI: 10.1016/j.ijpe.2013.02.031.
32. Peters, M., Campagnaro, P. (1996). Do women really excel over men in manual dexterity? *Journal of Experimental Psychology: Human Perception and Performance*, Vol. 5, pp. 1107-1112.
33. Rashid, Z., Rötting, M. (2021). Evaluation of manual skill degradation due to automation in apparel manufacturing. *Applied Sciences*, 11(23), 11098. DOI: 10.3390/app112311098
34. Salah, A., Çağlar, D., Zoubi, K. (2023). The impact of production and operations management practices in improving organizational performance: The mediating role of supply chain integration. *Sustainability*, Vol. 15 No. 20, p. 15140, DOI: 10.3390/su152015140.

35. Schmader, T., Johns, M., Forbes, C. (2008). An integrated process model of stereotype threat effects on performance. *Psychological Review*, 115(2), pp. 336-356. DOI: 10.1037/0033-295X.115.2.336.
36. Spencer, S.J., Steele, C.M., Quinn, D.M. (1999). Stereotype threat and women's math performance. *Journal of Experimental Social Psychology*, 35(1), pp. 4-28. DOI: 10.1006/jesp.1998.1373.
37. TalentUp (2023). *The cost of employee turnover*. TalentUp Blog, available at: <https://www.talentup.io>, 8 October 2024.
38. Wang, S., Sun, L. (2023). Does organizational performance affect employee turnover? A reexamination of the turnover-performance relationship. *Public Administration Review*, available at: <https://deepblue.lib.umich.edu>, 8 October 2024.
39. WebHR (2024). *The true cost of employee turnover*, available at: <https://web.hr/blog/true-cost-employee-turnover>, 8 October 2024.
40. Yücel, İ. (2021). Transformational leadership and turnover intentions: The mediating role of employee performance during the COVID-19 pandemic. *Administrative Sciences*, Vol. 11, No. 3, p. 81, DOI: <https://doi.org/10.3390/admsci11030081>.
41. Zakay, D., Wooller, S. (1984). Time pressure, training and decision effectiveness. *Ergonomics*, 27(3), pp. 273-284. DOI: <https://doi.org/10.1080/00140138408963489>.
42. Zemore, S.E., Fiske, S.T., Kim, H.J. (2000). Gender Stereotypes and the Dynamics of Social Interaction. In: R.K. Unger (Ed.), *The Developmental Social Psychology of Gender* (p. 35). Psychology Press, DOI: 10.4324/9781410605245.

AWARENESS AND DEVELOPMENT OF GREEN-BLUE INFRASTRUCTURE IN THE PROCESS OF URBAN MANAGEMENT IN THE GZM AREA IN THE LIGHT OF OWN RESEARCH

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Purpose: Aggressive urbanisation is drastically reducing the area of green-blue resources in cities, leading to threats of flooding from heavy rains and drought due to the high degree of pavement sealing. Setting a new direction for urban space management is becoming necessary, emphasising designating new areas for tree planting and water retention. To ensure this process's effectiveness, it is crucial to be aware of the importance and necessity of increasing green-blue infrastructure in urban spaces in the face of climate change. The purpose of this article is to present the results of a survey conducted among people holding public functions in local government, i.e. mayors, councillors, employees of offices, as well as residents of the Górnośląsko-Zagłębiowska Metropolia (GZM) regarding awareness of the importance and development of green-blue infrastructure in urban spaces in the process of city management.

Design/methodology/approach: The research problem is to identify the prevalence of certain beliefs and thoughts among residents and city and municipal leaders of the GZM regarding the importance and benefits of developing green-blue infrastructure in urban space. A quantitative research method (questionnaire survey) was used to carry out the research, as well as the method of analysis and criticism of the literature.

Findings: As a result of the analysis of the survey questionnaires filled out by respondents, it was discovered that residents see the need to take measures to develop blue-green infrastructure in the cities and municipalities of the GZM and consider them valuable. A particular group of residents - those who also hold a position in local government do not differ in their assessment of the issues studied from those who live in the GZM; they only declare greater knowledge of green-green infrastructure and actions taken by local governments in this regard.

Practical implications: The results of the research can support mayors in managing a city, taking into account concern for the comfort of residents in an increasingly urbanised area and exposure to various weather anomalies in urban space. **Social implications:** The study's results will help increase the belief that action is needed for climate adaptation and green-blue infrastructure development.

Originality /value: For several years, the scientific discourse on public management at the local level has seen a view of the need to adapt urban spaces to climate change. The research fills the knowledge gap in identifying the beliefs and thoughts of city and municipal leaders of the GZM, as well as residents' expectations regarding the development of public space, including the development of green-blue infrastructure.

Keywords: urban management, green-blue infrastructure, urban planning and management.

JEL Classification: R11, R58, H70.

1. Introduction

How urban space is developed results from many different conditions, and its effects are subject to evaluation and public acceptance. In the last decade, one can see a trend in urban space planning towards greater recognition of the role and importance of the natural environment in urban space (Valente de Macedo et al., 2021; Hou et al., 2024)¹. Unfortunately, the solutions put in place are not always sufficient due to a lack of awareness of the importance of green-blue infrastructure (GBI) in modern urban space.

Modern urban space management requires constant concern for diminishing natural resources and consistent replenishment by implementing new infrastructure, such as retention basins or rain gardens (Panagopoulos et al., 2018, pp. 9, 58). Modern urban management also involves the designation of areas for tree planting, the quantitative development of public green areas, and the dissemination of solutions to reduce the effects of so-called “concreting” (e.g., by creating *pocket parks*) so that greenery becomes an essential and integral city-creative factor. Actions taken by local governments in public spaces should be combined with support for grassroots residents’ initiatives to create a synergy between local authorities and residents.

In urban space management, implementation and maintenance costs play an essential role, which, in the case of nature-based solutions (NbS) are smaller than the costs of the so-called *grey* infrastructure (<http://ec.europa.eu>). However, awareness of this fact does not seem to be widespread among local government officials and residents.

Planning and management of urban space based on the development of green-blue natural and infrastructural resources is first and foremost:

- increasing the quantity of resources (creating new infrastructure),
- increasing the quality of resources (cleaning up the wooded areas),
- designating new infrastructural resources in the areas most affected by concretions (uncovering watercourses, creating rain gardens).

To effectively implement the measures mentioned above in urban space, it is necessary to start with their planning, which will be effective only when the local society is convinced of the rightness of their introduction. Therefore, it is reasonable to ask whether the city administrators and residents are convinced of the necessity of green-blue infrastructure development in modern city management. It is also important to diagnose what external and internal factors influence the local community’s beliefs about the causes of climate change in the modern world, the real and effective possibilities of counteracting it, and the broadly understood formation of spatial order. The research part attempted to answer these questions, preceded by a critical analysis of domestic and foreign literature on the importance of green-blue natural and infrastructural resources in urban space. The research part that presents the collected results for the first time ends the conclusions of the study.

¹ The maintenance and development of green-blue resources varies at the level of continents, countries, but also regions.

2. Literature Review

Urban space, especially the inner city, is a phenomenon that combines the interests of various stakeholder groups with different attitudes towards participation in the socio-spatial life of the city - property owners, residents and tourists (among them people with disabilities), but also entrepreneurs, corporations and environmentalists - whose expectations architects and urban planners are trying to put into practice. It is worth noting that a seemingly homogeneous group of residents of the same city may show radically different expectations of public space resulting, for example, from their age, family situation, material status or work. Every day in the urban space, the essential public life processes occur and intermingle with the private processes - on a strongly differentiated and large scale, creating a complex and unique urban structure. L. Wirth defined urban space as a compilation of 3 components – *society, technology and ecological order* while noting the multiplicity and diversity of attitudes, as well as social perceptions (Wirth, 1996). Conscious and rational management of urban space originates in the beliefs of the entire collective of the local community, which are changing due to various factors. Therefore, it is expedient to learn about them and shape them in a way that is appropriate to the following climate changes, keeping in mind the concern for the common good. A. Harasimowicz represents a similar voice, noting the need to create environmental infrastructure in urban space, which involves an inevitable increase in public spending (Harasimowicz, 2015, p. 27). Unlike urban areas, rural space does not interfere so drastically with the natural environment, which will result in less social tension in the approach to public space development. S. Gzell rightly notes that the discourse on the city and its future is moving toward the conclusion that regardless of the factors analysed, policies and development plans cannot depend solely on the work of so-called narrow specialists and experts. The interpretation of urban development must be characterised by holistic intersectoral integration, assuming (Kmak, 2018, p. 137):

- *in economics* – taking care to meet actual needs, not whims,
- *in relation to nature* – sustainability,
- *in technology* – relying on the best use of human knowledge,
- *in the creation of institutional order* – applying the principles of decentralisation and subsidiarity,
- *in achieving spatial order* – creating socially agreed instruments.

The shaping of urban space, including the development of green-blue natural and infrastructural resources, should be carried out so that residents are convinced of the expediency of the measures taken and accept them. It is also important to make residents aware that investments in this area respond to real, local and global needs in the context of climate change adaptation (*e.g., as part of ongoing public consultations or information campaigns*).

Urban space management (Naumann et al., 2020, p. 6)² focused on improving the quality of the urban natural environment due to the following reasons:

- the need to take action in the area of adaptation to climate change is occurring with increasing intensity. Given the high concentration of people and infrastructure, urban spaces are particularly vulnerable to the negative effects of these changes. Each city, due to its unique and diverse characteristics (social, spatial, economic), has a different vulnerability to the effects of climate change (Hill et al., 2011, p. 13)³,
- the positive impact of the city's green-blue resources on the life and functioning of modern residents (Song, 2018),
- the need to increase the efficiency of public spending by synchronising and synergising the implementation of multiple objectives contributing to sustainable spatial development (so-called integrated urban development concepts).

According to a study conducted by Public for Spaces, developed urban space affects the quality of life and health of residents, attracts investment and develops entrepreneurship, becomes a venue for cultural events, develops tourism, improves safety and a sense of security, and determines the level of self-organisation of society (Stangel, 2013). A. Hołub points out that urban space is becoming a consumer good, which is related to the increasing number of events held in public spaces and the fact that the public is looking for places that guarantee them a high sense of security (Hołub, 2005). In turn, scientific research confirms that climate change is occurring and will intensify in urban areas, and its symptoms will intensify (IPPC, 2018).

3. Methods

A quantitative survey was conducted using the CAWI method between 9.06 and 27.08.2024. The link to the questionnaire was sent out electronically to representatives holding local government functions and residents in 40 cities and municipalities in the GZM. The survey questionnaire was sent to the official e-mail addresses of city and municipality mayors, while to residents – mainly students and lecturers, the distribution was carried out through the staff of the WSB Academy in Dąbrowa Górnicza.

² It is increasingly referred to in the literature as urban management, emphasising an interdisciplinary and coordinated approach. It is increasingly proposed to understand urban planning as a discipline not limited to spatial issues but encompassing the complex context of processes, structures and problems of the urban environment and its impact on residents.

³ E. Hill and a group of researchers point to what is known as a resilience path. If a negative event occurs and the city maintains its growth path (growth path), the city is considered shock-resistant. In a situation where the occurrence of a negative event affects the direction of the city's growth path, however, assuming that the city rebuilds its growth capacity after suffering a shock, it is considered resilient (resilient). In the event that it does not rebuild its development capacity, it is a non-resilient city.

As a result of the completed surveys, a total of 90 surveys were received back, i.e. 83 complete surveys (with no missing data) and seven surveys in which at least seven questions were completed (in addition to the metric questions) – 51 surveys were from residents who do not have a public function in the local government, 39 surveys from residents who are also representatives of the local government. The maximum error of estimation for the entire sample of respondents ($n = 90$), assuming the size of the GZM population at 2 million 250 thousand residents, is 10% at a confidence level of 95%. As a result of an intensive campaign to obtain completed questionnaires addressed to representatives of 41 cities and municipalities forming the GZM, we reached 24. This means that a satisfactory survey return of 59% was achieved. The largest number of responses came from Dąbrowa Górnicza ($n = 4$), Katowice and Piekary Śląskie ($n = 3$). One or two surveys each came from the other cities. The surveys included 13 chiefs or employees responsible for environmental affairs, nine chiefs or employees responsible for investment and infrastructure development, eight mayors, four councillors, three chiefs/employees responsible for urban planning, and two deputy mayors. The largest proportion of respondents had been in office for more than 15 years (38.5%), up to 3 years (20.5%) or between 5 and 10 years (18%).

Table 1.

Spatial structure of respondents who took part in the survey

No.	City of performing local government functions	N	No.	City of performing local government functions	n
1	Będzin	1	14	Piekary Śląskie	3
2	Bieruń	2	15	Pilchowice	1
3	Bobrowniki	2	16	Pyskowice	1
4	Bojszowy	1	17	Radzionków	1
5	Czeladź	2	18	Ruda Śląska	1
6	Dąbrowa Górnicza	4	19	Siemianowice Śląskie	1
7	Katowice	3	20	Siewierz	1
8	Kobiór	1	21	Sławków	1
9	Lędziny	1	22	Sośnicowice	1
10	Łaziska Górne	2	23	Zabrze	2
11	Mierzęcice	2	24	Zbrosławice	1
12	Mikołów	1	25	<i>Not indicated</i>	2
13	Ożarówice	1		Total	39

Source: own elaboration based on the collected data.

The sociodemographic characteristics of the respondents are shown in Table 2. The statement in bold shows the dominant category.

Table 2.*Sociodemographic characteristics of respondents who took part in the survey*

	Local government officials n (%)	Residents n (%)
Age		
26-35	8 (21)	15 (29)
36-45	10 (26)	11 (22)
46-55	13 (33)	17 (33)
56-65	6 (15)	8 (16)
65+	2 (5)	0 (0)
Marital status		
married	34 (87)	17 (33)
single	3 (8)	17 (33)
in a civil partnership	1 (3)	13 (25)
divorced/separated	1 (3)	4 (8)
Having children		
none	4 (10)	31 (61)
one	21 (54)	11 (22)
two	12 (31)	9 (18)
three	2 (5)	0 (0)
Attitude towards faith and church		
I am a nonbeliever, and I am not interested in matters of faith and religion.	1 (3)	4 (8)
I am a nonbeliever because I believe that the teachings of the churches are wrong.	0 (0)	5 (10)
I am a believer, and I follow the church's instructions	6 (15)	9 (18)
I am a believer, but I practice my faith in my own way	12 (31)	19 (37)
I do not want to answer	20 (51)	14 (27)

Source: own compilation based on collected data.

The questions in the submitted survey questionnaire addressed the following issues:

1. beliefs related to ecology and climate change (determining the level of importance of taking pro-environmental actions, declaring the perception of climate change and determining its causes, determining the factors affecting the formation of attitudes towards ecology),
2. knowledge of green-blue infrastructure (ability to define what GBI is and what its functions are, knowledge of the implementation of GBI investments and their evaluation),
3. beliefs about the development of green-blue infrastructure (recognising the positive impact of GBI on urban space and counteracting climate change, and identifying the benefits of GBI development),
4. priorities of the local government (selecting priority tasks for the local government and determining the position of GBI development among them, determining the legitimacy of financing GBI development from the city budget),
5. activities related to developing green-blue infrastructure and their importance (determining the legitimacy and urgency of preventing climate change, determining the importance and how to shape GBI).

The study focused on testing the differences between the studied groups and presenting their views on environmental issues and green-blue infrastructure development. It was hypothesised that there are differences between residents and representatives in public office in their beliefs about the importance of pro-environmental measures, their assessment of the legitimacy of undertaking green-blue infrastructure development, and their knowledge of the BGI issue. It was assumed that local government officials would be more knowledgeable about BGI issues and its functions, more convinced of the positive consequences of BGI development, and consequently more likely to declare the need to carry out related tasks. On the other hand, it was assumed that there would be no differences in beliefs related to climate change and the need to counteract it, as well as with regard to factors shaping pro-environmental attitudes.

4. Results

The results of the conducted research are divided into five parts, which are as follows:

a) Beliefs related to ecology and climate change

Nine out of ten total respondents (91%) indicated that **it was important to some degree for them to take pro-environmental measures in their daily lives** (45.5% - rather important, 45.5% - definitely important). The responses did not differ significantly between the groups of respondents - residents and local government officials (Chi-square $p < 0.05$). It was similar to the answers to the question, **"Do you notice any negative climate changes taking place in the modern world?"**. A total of 82% indicated that they do. Nearly half (47%) answered "definitely yes".

Overall, the factors that had **the greatest influence on the respondents' present attitude toward ecology** were observation of environmental changes (61% of respondents), life experiences (41%), upbringing and rules in the family home (40%), school education (29%), acquired education (28%), and social pro-environmental campaigns (23%). Less than 15% of respondents selected other factors.

Of the listed weather phenomena, the general public considered the following to be **the greatest threat**: heavy rains causing flooding and waterlogging (57% of respondents), heat (52%), drought (37%), as well as strong, gusty winds (28%) and hailstorms (23%). Other phenomena were selected by less than 20% of respondents.

A significantly higher percentage of residents indicated that inconvenient weather events affected immediate family members (29% vs. 8%). On the other hand, local residents were more likely to deny having suffered from weather phenomena (72% vs. 45%). The study groups did not differ significantly in terms of self-declaration (Chi-square $p > 0.05$).

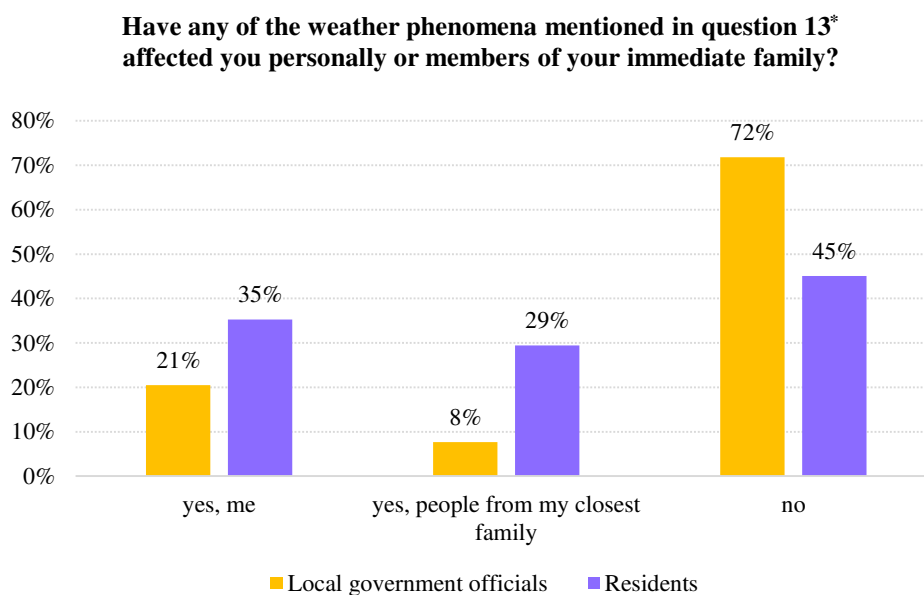


Figure 1. Beliefs related to ecology and climate change.

Source: own compilation based on collected data.

Half of the respondents (51%) were of the opinion that **the effects of nuisance weather phenomena can be effectively prevented at the local or regional level**—36% answered "rather yes", 16% answered "definitely yes". One in ten respondents (12%) indicated that determining this was difficult for them. In this case, the responses of residents and local government officials were very similar.

In response to the question "**who do you think is responsible for climate change in the modern world?**" the highest percentages of respondents overall chose the following answers: companies and industries (46%), global corporations (44%), the public (44%), national policymakers (31%), naturally occurring climate processes (30%). Other responses were selected by less than 10% of respondents.

b) Knowledge of green-blue infrastructure

A significant difference between the groups of respondents can be demonstrated with regard to questions concerning **knowledge of GBI** – what it is and what functions it performs (Chi-square $p < 0.05$; Mann-Whitney U $p < 0.05$). Here, as expected, local government officials are the group that was far less likely to declare that they could not identify these two issues.

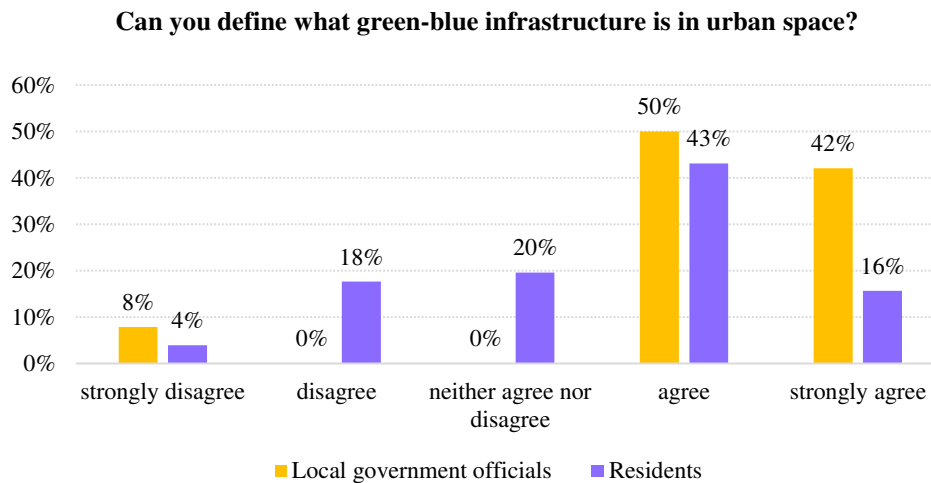


Figure 2. Knowledge of green-blue infrastructure (1).

Source: own compilation based on collected data.

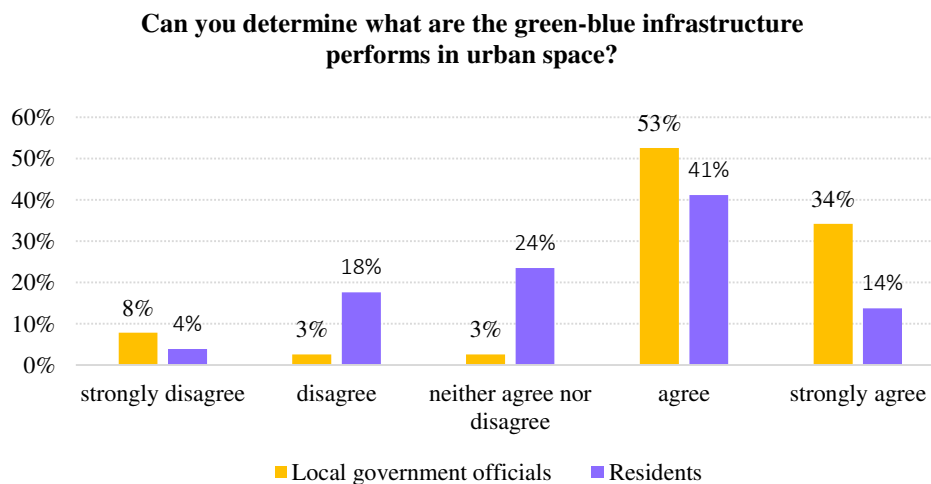


Figure 3. Knowledge of green-blue infrastructure (2).

Source: own compilation based on collected data.

The surveyed groups also differ in indicating **whether green-blue infrastructure investments have been made in their city** (Chi-square $p < 0.01$; Cramer's V: 0.4; $p = 0.01$). According to 42% of local government officials, they have been implemented. More than half of the residents had no knowledge of this.

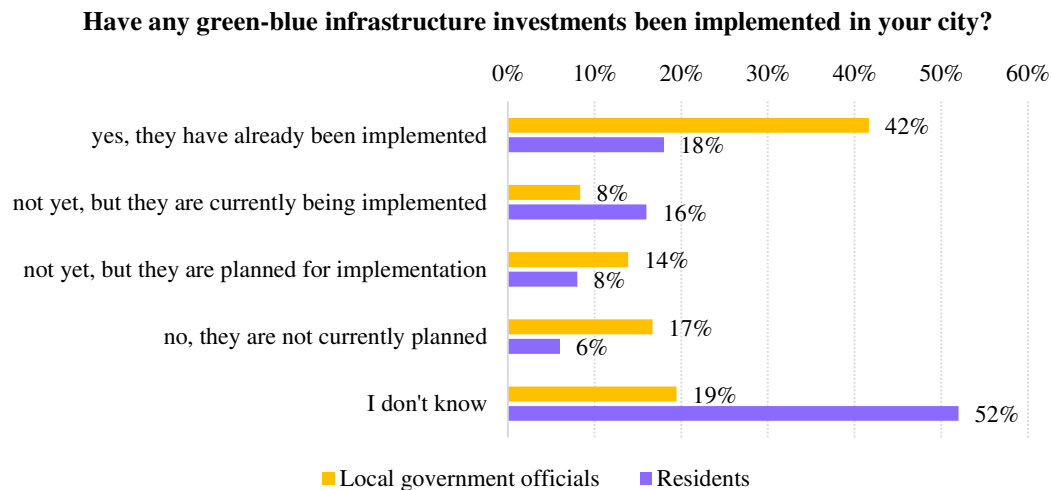


Figure 4. Knowledge of green-blue infrastructure (2).

Source: own compilation based on collected data.

The **assessment of whether the investments made are sufficient** (the answer was given only by respondents who indicated that investments are currently being made or have been made before) does not differ significantly (Chi-square $p > 0.05$) between the groups of respondents. Opinions are divided —40% considered GBI investments insufficient, 37% sufficient, and slightly more than one-fifth (23%) hesitated.

c) Beliefs about green-blue infrastructure development

Respondents, regardless of the group (Chi-square $p > 0.05$), believe that the development of **GBI can improve the comfort of living in urban space** (97% positive responses overall), **impact climate change adaptation** (86%), **counteract negative climate change** (84%), and **reduce the carbon footprint** (71%). If GBI is shaped in the right way, according to respondents, **it can influence local sustainability in urban space** (91%).

Among the benefits that respondents thought GBI development could bring were water retention (69% of respondents indicated this answer), water, air and soil purification (49%), and improved scenic qualities and potential for tourism and recreation development (48%) were the most frequently cited.

d) Priorities of the local government

Green-blue infrastructure development was ranked first among the five areas of choice. According to more than two-thirds of respondents (69%), it is a priority. In second place with a slightly lower percentage (62%) was the development of road infrastructure conditioning safety improvements. The only area on which the surveyed groups differed (Chi-square $p < 0.05$) was the development of administration, particularly e-government services - according to 16% of residents and 0% of local government officials, it should be prioritised.

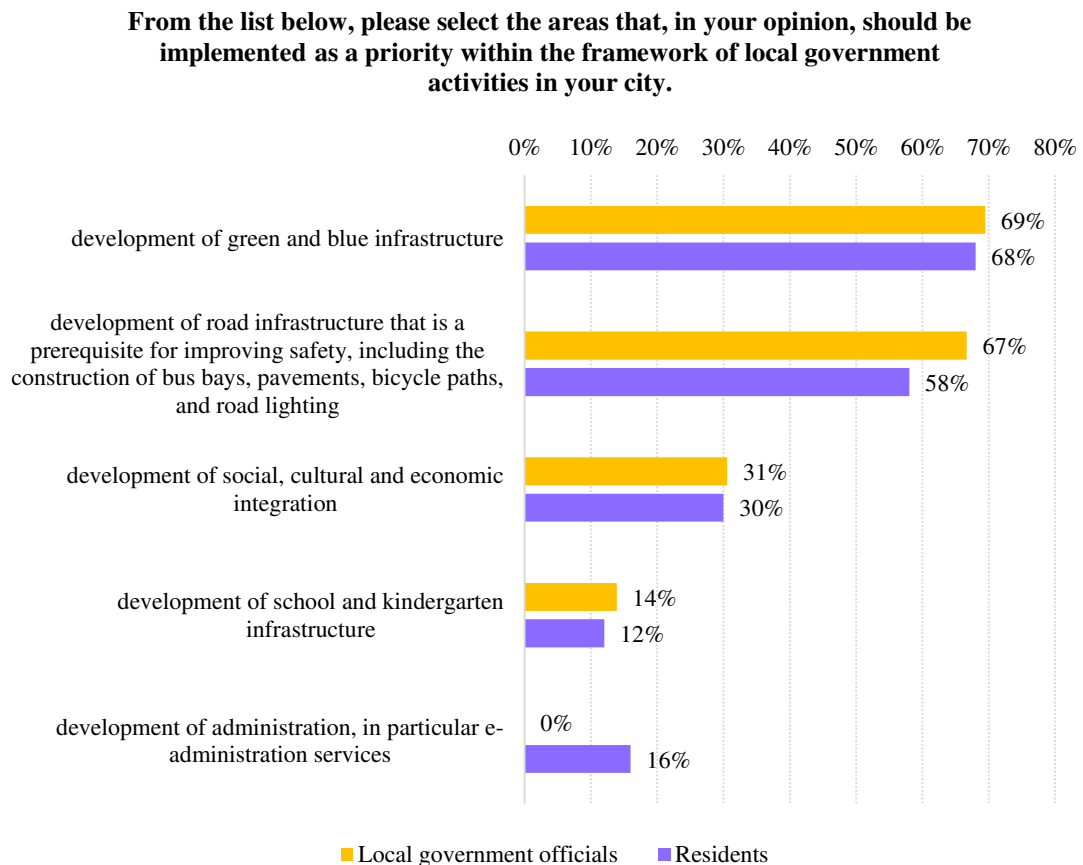


Figure 5. Priorities of the local government.

Source: own compilation based on collected data.

Regardless of the group, respondents also agreed **that developing green-blue infrastructure due to modern climate change should be an absolute priority within the framework of local government activities**. Nearly three-quarters of respondents (73%) agreed with this statement, while one in ten respondents (10%) held the opposite view.

A slightly lower percentage of respondents declared that **the development of green-blue infrastructure, in the absence of direct needs and expectations reported in this regard by residents, should be financed and implemented from the city or municipal budget**. Among the responses, “rather yes” (37%) and “definitely yes” (30%) prevailed - bringing the total to two-thirds of those convinced of this need (67%). One in five respondents (20%) had no definite opinion on this issue (answer “neither no nor yes”).

e) Green-blue infrastructure development activities

Regardless of the group, respondents agreed that **the GZM area requires urgent action to adapt to climate change**. Half of the respondents (49% overall) answered "rather yes", while a third (32%) answered "definitely yes". The opposite view was held by 7% of respondents. Respondents were also convinced that developing **green-blue infrastructure in their city requires expert support**. More than half indicated that there was rather such a need (54%). One-third were strongly convinced of this (33%).

Among the **landscape elements that respondents believe should create green-blue infrastructure in urban space**, respondents primarily identified squares and city parks (59%), strips of trees and shrubs—including rows along roads and avenues (48%), bodies of water (43%), and rain gardens (34%).

Due to undertaking GBI tasks as part of their professional activities, self-government respondents were significantly more likely to declare initiating the implementation of such activities (31% vs. 6%). Residents were significantly more likely to indicate that they neither support nor initiate such activities (46% vs. 22%). In contrast, the surveyed groups did not differ in their support for GBI-related activities.

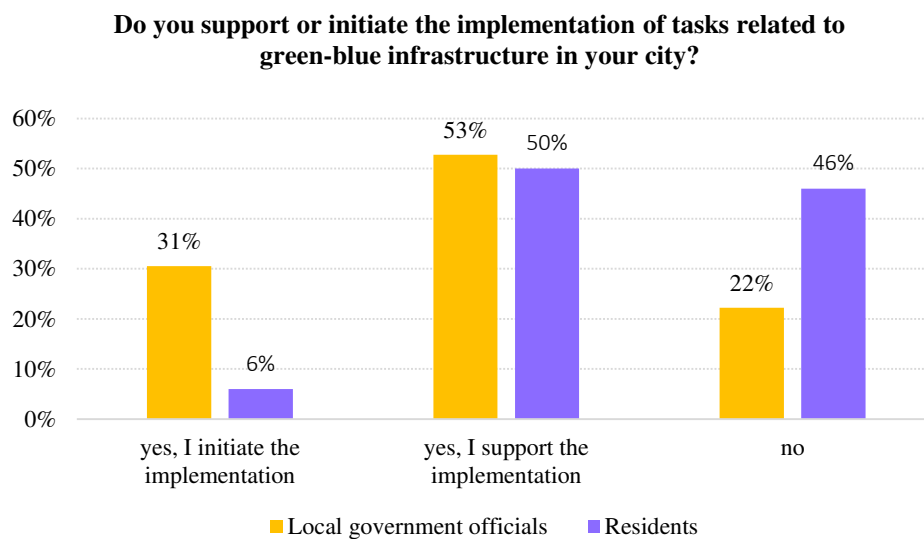


Figure 6. Green-blue infrastructure development activities (1).

Source: own compilation based on collected data.

The respondent groups - residents and local government officials - **did not differ in their assessment of the importance of shaping green-blue infrastructure in contemporary urban space to reduce the effects of climate change** (Chi-square: $p > 0.05$; Mann-Whitney U: $p > 0.05$). Both groups are convinced of the importance of shaping the GBI, with “rather important” (46% among local government officials and 44% among residents) and “definitely important” (41 and 44%) prevailing among the responses.

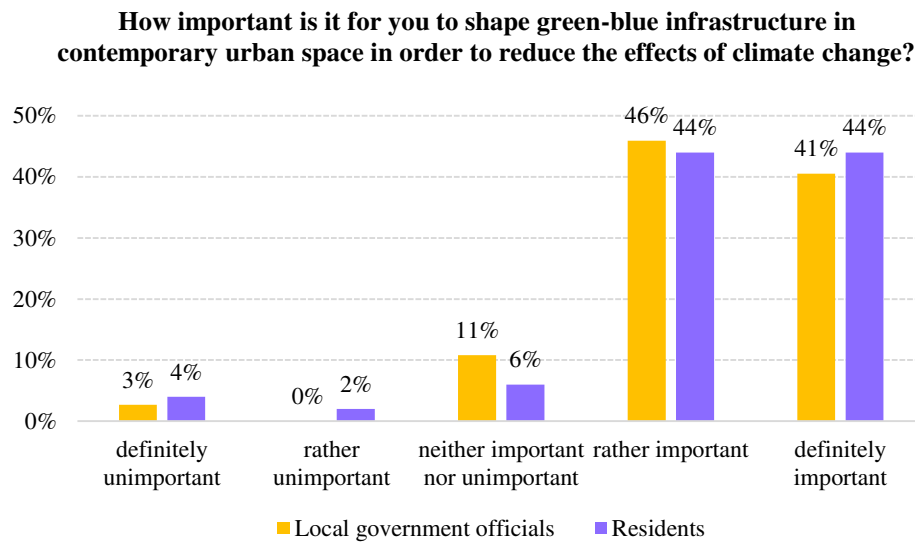


Figure 7. Green-blue infrastructure development activities (2).

Source: own compilation based on collected data.

Among local government officials, perceptions of the level of importance of shaping green-blue infrastructure in contemporary urban space to reduce the effects of climate change were primarily related to whether proper shaping of green-blue infrastructure can affect local sustainability in the city of residence (Sperman's Rho: 0.59; $p < 0.01$), whether GBI development can counteract negative climate change (Sperman's rho: 0.54; $p < 0.01$), and whether it has an impact on climate change adaptation (Sperman's rho: 0.53; $p < 0.01$). A significant relationship was also shown with respondents' declaration of perceiving negative climate change occurring worldwide (Sperman's rho: 0.53; $p < 0.01$). Also significant was the ability to define what green-blue infrastructure is in urban space (Spearman's rho: 0.58; $p < 0.01$) and what its functions are (Spearman's rho: 0.52; $p < 0.01$) and whether the respondent answered in the negative to the question regarding supporting or initiating the implementation of green-blue infrastructure tasks (Cramer's V: 0.57; $p = 0.01$).

Among residents, the assessment of the level of importance of shaping green-blue infrastructure in contemporary urban space in order to reduce the effects of climate change was primarily related to the perception of whether the proper shaping of green-blue infrastructure can have an impact on sustainable local development in the city of residence (Sperman's rho: 0.56; $p < 0.01$) and whether the development of GBI can improve the comfort of life in urban space (Sperman's rho: 0.52; $p < 0.01$). For residents, unlike local government officials, the declared level of knowledge about GBI was not associated with the assessment of the level of importance of shaping GBI in urban space ($p > 0.05$). No relationship was also demonstrated in relation to the assessment of the importance of taking pro-ecological actions in everyday life ($p = 0.06$).

In both groups, none of the studied sociodemographic characteristics (age, marital status, number of children, attitude to religion, functions held in local government and the time of performing them) showed any significant correlation with the assessment of the importance of shaping green and blue infrastructure.

The correlation coefficients for all studied factors are presented in Tables 3 and 4.

Table 3.

The correlation coefficients for all studied factors (1)

How important is it for you to shape green-blue infrastructure in contemporary urban space in order to reduce the effects of climate change?	Local government officials			Residents		
	Spearman's rho	P	N	Spearman's rho	p	n
Do you think proper green and blue infrastructure shaping can impact sustainable local development in your city?	0,59	0,00	36	0,56	0,00	50
Are you able to define what green-blue infrastructure is in urban space?	0,58	0,00	37	0,14	0,34	50
Can developing green-blue infrastructure in urban spaces, such as retention reservoirs, rain gardens, permeable surfaces, and green areas, counteract negative climate change?	0,54	0,00	37	0,40	0,00	50
Do you notice any negative climate changes taking place in the modern world?	0,53	0,00	37	0,50	0,00	50
In your opinion, does the development of green and blue infrastructure in your city impact adaptation to climate change?	0,53	0,00	34	0,46	0,00	49
Can you determine what functions the green-blue infrastructure performs in urban space?	0,52	0,00	37	0,03	0,84	50
How important is it for you to undertake pro-ecological (environmental) activities in your everyday life?	0,50	0,00	37	0,26	0,06	50
In your opinion, due to contemporary climate change, should the development of green and blue infrastructure be an absolute priority within the framework of local government activities in your city?	0,45	0,01	36	0,39	0,01	50
Do you think that the GZM area requires urgent action to adapt to climate change?	0,44	0,01	37	0,49	0,00	50
Do you think that the development of green and blue infrastructure can improve the comfort of life in urban spaces?	0,37	0,03	37	0,52	0,00	50
In your opinion, should the development of green and blue infrastructure be financed and implemented from the city budget in the absence of direct needs reported by residents?	0,25	0,14	36	0,22	0,12	50
Do you think that the area of the GZM is a friendly place to live?	0,22	0,19	37	-0,04	0,76	50
Do you think that the effects of the weather phenomena mentioned in question 13 can be effectively prevented at the local or regional level?	0,02	0,92	37	0,30	0,04	50
In your opinion, does the development of green and blue infrastructure in your city require support in the form of expert knowledge?	0,22	0,20	34	0,27	0,06	49
In your opinion, does developing green and blue infrastructure in your city impact reducing the carbon footprint?	0,23	0,19	34	0,38	0,01	49

Table 4.*The correlation coefficients for all studied factors (2)*

How important is it for you to shape green-blue infrastructure in contemporary urban space in order to reduce the effects of climate change?	Local government officials			Residents		
	Phi/Cramer's V	P	n	Phi/Cramer's V	p	n
How old are you?	0,64/0,37	0,08	37	0,37/0,26	0,55	50
What is your marital status?	0,55/0,32	0,28	37	0,56/0,32	0,21	50
Do you have children?	0,50/ 0,29	0,41	37	0,28/0,20	0,86	50
Which of the following descriptions [of religiosity] best fits your situation?	0,44/0,31	0,49	18	0,55/0,39	0,21	36
What is your role in local government?	0,55/0,32	0,51	37	n/a	n/a	n/a
How long have you been working in the indicated position in local government?	0,54/0,31	0,56	37	n/a	n/a	n/a
Have any green-blue infrastructure investments been implemented in your city?	0,70/0,40	0,13	36	0,75/0,37	0,03	50
Do you think investments in your city's green and blue infrastructure are sufficient?	0,55/0,39	0,71	18	0,70/0,40	0,51	17
Do you support or initiate the implementation of GBI tasks in your city? [yes, it initiates the implementation]	0,38/0,38	0,17	36	0,13/0,13	0,93	50
Do you support or initiate the implementation of GBI tasks in your city? [yes, I support the implementation]	0,38/0,38	0,17	36	0,26/0,26	0,48	50
Do you support or initiate the implementation of GBI tasks in your city? [no]	0,57/0,57	0,01	36	0,25/0,25	0,52	50

5. Conclusions

The analysed survey results allowed us to establish the lack of differences between the surveyed groups, i.e. residents of GZM who do not hold a public office in local government and residents who are also representatives of local government authorities. Among the residents, both the level of acceptance of solutions in the field of green-blue infrastructure, as well as the assessment of the necessity of its development and the belief in its effectiveness, were high. Residents see the positive effects of implementing GBI solutions and recognise their potential in the field of environmental protection and combating climate change. The development of green-blue infrastructure was considered a priority among the authorities' activities. There was also strong support for financing such activities from the city budget. Another argument may also be the perception of the urgency of actions related to adaptation to climate change in the GZM area. Therefore, it can be assumed that among the residents of GZM, there is a high awareness of the justification for GBI actions and a high potential for supporting them. It is also possible to define the area of support for the authorities' activities through grassroots initiatives undertaken by residents as a development area.

In the context of GBI, the role of local government officials – apart from their professional activity directly related to infrastructure development – can be seen primarily in providing current information on planned and implemented investments in the field of GBI and justifying the actions taken – with an emphasis on the positive consequences of GBI. Next, local government officials should provide knowledge of what green-blue infrastructure is and what its functions are. Additionally, in these roles, local government officials can be supported by experts in climate policy, sustainable development, urban planning and urban infrastructure planning. From the perspective of residents, in practice, the development of GBI should focus primarily on preventing weather phenomena such as floods and droughts – currently considered the greatest threats.

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References

1. Gzell, S. (2018). Praktyka planistyczna, a naukowe metody badania miasta. In: M. Kmak, Zarządzanie przestrzenią miasta - wybrane aspekty. *Przedsiębiorczość i Zarządzanie*, vol. XIX, no. 4, Part II. SAN Publishing, p. 137.
2. Harasimowicz, A. (2015). Efekty aglomeracji -czynnik czy bariera rozwoju miast? Analiza wybranych aspektów w świetle literatury przedmiotu. *Studia Miejskie*, No. 20, p. 27.
3. Hill, E., Clair, T.S., Wial, H., Wolman, H., Atkins, P., Blumenthal, P., Ficenec, S., Friedhoff, A. (2011). *Economic Shocks and Regional Economic Resilience*. Building Resilient Regions, Institute of Governmental Studies, University of California, p. 13.
4. Hołub, A. (2005). Współczesna przestrzeń publiczna. In: M. Kochanowski (ed.), *Przestrzeń publiczna miasta postindustrialnego*. Gdańsk: Wydawnictwo Urbanista.
5. Hou, W., Li, X. (2024). Assessing urban green infrastructure: A simple and practical measure of its spatial distribution equity and a comprehensive evaluation. *Ecological Indicators*, vol. 158. Retrieved from: <https://doi.org/10.1016/j.ecolind.2023.111408>.
6. http://ec.europa.eu/environment/nature/ecosystems/index_en.htm, 6.01.2024.

7. Naumann, S., Davis, M., Iwaszuk, E., Freundt, M., Mederake, L. (2020). *Błękitno-zielona infrastruktura dla łagodzenia zmian klimatu w miastach*. Ecologic Institute & Fundacja Sendzimira, p. 6.
8. Panagopoulos, T., Jankovska, I., Boştenaru Dan, M. (2018). *Urban green infrastructure: The role of urban agriculture in city resilience*. Urban. Arhit. Constr., pp. 9, 58.
9. Song, C., Ikei, H., Miyazaki, Y. (2018). Physiological Effects of Visual Stimulation with Forest Imagery. *Int. J. Environ. Res. Public Health*, 15(2). Retrieved from: <https://doi.org/10.3390/ijerph15020213>
10. Special Report on Global Warming of 1.5 °C (2018). Intergovernmental Panel on Climate Change (IPPC).
11. Stangel, M. (2013). *Kształtowanie współczesnych obszarów miejskich w kontekście zrównoważonego rozwoju*. Gliwice: Wydawnictwo Politechniki Śląskiej.
12. Valente de Macedo, L., Picavet, M., Puppim de Oliveira, J., Shih, W. (2021). Urban green and blue infrastructure: A critical analysis of research on developing countries. *Journal of Cleaner Production*, vol. 313. Retrieved from: <https://doi.org/10.1016/j.jclepro.2021.127898>
13. Wirth, L. (1996). Urbanism as a Way of Life. *The American Journal of Sociology*, vol. 44, no. 1.

SAFE-HAVEN CURRENCIES DURING FINANCIAL MARKET INSTABILITY IN THE 21ST CENTURY

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Purpose: The aim of this article is to verify whether the Swiss franc (CHF), the US dollar (USD), and the Japanese yen (JPY) continue to function as safe haven currencies in the financial markets of the 21st century.

Design/methodology/approach: Analysis of correlations of logarithmic returns of major currency indices with the S&P 500 index during periods of financial instability and additional verification of net positions of selected market participants.

Findings: Based on the analysis of the return correlations of CHF, JPY, and USD with the S&P 500 during periods of heightened uncertainty in the 21st century, these currencies still serve as safe havens. However, the net positions of large speculators in the futures markets do not confirm that this is being utilized.

Practical implications: The conclusions may help both businesses and individuals stabilize portfolio volatility during periods of heightened uncertainty in financial markets.

Social implications: Conclusions may help mitigate social inequalities arising during financial crises by appropriate currency diversification of held assets.

Originality/value: The research comprehensively addresses the current situation during periods of heightened volatility in the 21st century. Additionally, the analysis of return correlations is supplemented by verification of net positions in the futures market using commitment of traders reports. This work is directed towards businesses, households investing surplus finances, and financial institutions.

Keywords: currency market, financial crises, investments, diversification.

Category of the paper: Research paper.

1. Introduction

During periods of financial market instability, the vast majority of financial assets lose value. This leads to a decrease in the value of investment portfolios for investors who allocate their capital to instruments negatively correlated with increased market uncertainty. However, not all instruments move in the same direction during these times. Some appreciate in value during periods of instability and are negatively correlated with the market, thereby acquiring

the designation of safe havens. These assets help preserve portfolio value during downturns, including economic crises accompanied by panic sell-offs in financial markets.

The paper describes the behaviour of safe-haven currencies during periods of financial market instability in the 21st century. According to the proposed hypothesis, the US dollar, the Swiss franc and the Japanese yen should show a lack of positive correlation with the stock market in the 21st century.

To verify the hypothesis, a correlation of logarithmic rates of return analysis of major currency indices with the S&P 500 index was conducted. Six periods characterized by above-average volatility in financial markets in the 21st century were analyzed. The selected events included the Dotcom bubble burst, the 2007 financial crisis, the Eurozone crisis, the US-China trade wars, COVID-19 pandemic and bear market in 2022. The examined correlations were based on the weekly returns of major currency indices and the S&P 500 index. To deepen the analysis, the positions of non-commercial entities on selected currency pair futures contracts were also examined during the given periods.

The primary objective of this paper is to determine whether the US dollar, Japanese yen, and Swiss franc have served as safe haven assets during periods of financial market instability in the 21st century. The research objectives include analyzing the behavior of key market participants in the foreign exchange market during times of heightened uncertainty and examining the performance of the US dollar, Swiss franc, and Japanese yen in comparison to other major currencies during such periods.

The article continues the analysis in this area by providing new empirical data based on current events that have had a high significance for the volatility of financial markets. It also combines the analysis of changes in futures positions. The combination of correlation analysis and the accompanying changes in the number of contracts is an original approach in the analysis of the safe haven currency area.

The conclusions from the study may be useful both in the active investment process and in mitigating the currency exposure of enterprises and households.

2. The role of safe haven assets in risk-averse investment strategies

Increasing risk aversion and heightened tensions in financial markets significantly influence changes in investors' portfolios. These factors lead to a reduction in holdings of riskier investments in favor of safer ones. For instance, in 2007, as issues began to emerge in the interbank market, investors displayed a tendency to flee to high-quality assets (run for quality) and highly liquid assets (run for liquidity) (González-Hermosillo, Hesse, 2009). This flight to quality was reflected in the price of gold, which rose from \$660 in August 2007 to around \$1000 in the first quarter of 2008. The flight to liquidity, on the other hand, is associated with the

occurrence of liquidity spirals, particularly loss spirals, margin spirals, and asset value reductions (haircuts) (Brunnermeier, 2010).

During periods of heightened risk aversion, investors tend to focus on high-quality assets that offer greater safety or liquidity. Such investments are referred to as safe havens. They are characterized by either a lack of correlation or a negative correlation in their returns relative to other assets and portfolios during times of financial market turmoil (Baur, Lucey, 2010). A defining feature of safe haven assets is their negative correlation with a portfolio during extreme market conditions. This characteristic does not necessitate a generally positive or negative correlation but requires it to be zero or negative during specific periods. Therefore, in normal times, the correlation can take any value.

When safe haven assets are negatively correlated with another asset or portfolio under adverse market conditions, they compensate for investor losses, as their price increases when the price of another asset or portfolio decreases. Based on the return correlation with traditional investments, safe haven assets can be categorized into (Baur, Lucey, 2010):

- **Hedge investments:** Investments with returns that are either uncorrelated or negatively correlated with the primary investment's return. They do not necessarily reduce losses during market stress or turmoil, as their classification is based on the average correlation coefficient over the entire period.
- **Diversifier investments:** Investments with a weak positive correlation with the primary investment's return. Similar to hedge investments, they do not necessarily reduce losses during financial market turbulence, as the correlation coefficient used for classification is averaged over time. Every hedge investment also serves as a diversifier.
- **Safe haven investments:** Investments with a negative correlation with the primary investment during periods of financial market instability.

In the work of D.G. Baur and T.K. McDermott (Baur, McDermott, 2010), a more detailed distinction is made between strong and weak safe havens. According to this classification, a strong safe haven is negatively correlated with the portfolio during periods of market uncertainty. A weak safe haven, on the other hand, meets the condition of having no correlation with other portfolio assets during uncertain times. In such cases, the investment may not generate profits during unstable periods but can serve as a diversifying asset that reduces risk. It protects investors by not losing value in response to negative market shocks.

A safe haven is thus defined as an asset that allows investors to either generate profits or limit portfolio losses during periods of heightened uncertainty. Numerous studies in the literature address this issue, and various types of investments have been tested to determine their classification as safe havens. Selected literature on safe haven assets is presented in Table 1.

Table 1.*Types of Assets Considered as Safe Havens*

References	Type of assets
(Baur, Lucey, 2010), (Baur, McDermott, 2010), (Joy, 2011), (Anand, Madhogaria, 2012), (Reboredo, 2013a), (Reboredo, 2013b), (Ranaldo, Soderlind, 2010)	Gold
(Roache, Rossi, 2010)	CHF, JPY
(Hood, Malik, 2013)	Gold, palladium, platinum
(Ciner, Gurdgiev, Lucey, 2013)	Gold and other precious metals, as well as the VIX index crude oil, gold, US dollar, British pound, US and British bonds, US and British stock exchanges

Source: Potrykus, 2015, p. 196.

As shown in Table 1, the concept of safe havens is discussed in numerous studies. There is also a range of considerations regarding other instruments, including less conventional ones such as derivatives and cryptocurrencies (e.g., analyses of the use of credit default swaps (Ratner, Chiu, 2013) or cryptocurrencies (Bouri et al., 2017; Przyłuska-Schmitt, Jegorow, Bučková, 2022) as safe havens).

Assets with the status of a safe haven are usually characterized by certain features, including liquidity, functionality, limited supply, certainty of demand and durability (Admiral Markets, 2024). They encourage and convince investors to hold given instruments in uncertain times. An important factor for investors may also be the fact that given assets have repeatedly confirmed their safe nature in the past, during increased global risk aversion.

3. Research methodology

For the purpose of the analysis, weekly data was collected for the years 2020-2023 on the valuations of the currency indices CHF_I, JPY_I, USD_I, AUD_I, EUR_I, GBP_I, CAD_I, as well as the VIX index and the S&P 500 index. Based on this data, logarithmic returns for these indices were calculated.

Based on the standard deviation of returns for the S&P 500 index and the average weekly change in the VIX index, six periods of heightened volatility were identified for more detailed analysis. The timeframe of each event was determined from the highest weekly closing of the S&P 500 index to the lowest closing, occurring near the event. Each of these periods showed a higher standard deviation value than the average for the entire period, with an increase of 2.5%.

Subsequently, correlations between the returns of major currency indices and the S&P 500 index were calculated for the identified periods of heightened volatility and for the entire dataset.

After obtaining these data, the weighted average by the number of considered weeks and the arithmetic mean correlation of logarithmic returns of the analyzed currency indices during the examined periods were calculated. This aims to better illustrate overall trends and compare the behavior of selected currencies during periods of heightened uncertainty with their average behavior

To deepen the analysis of the behavior of financial entities during times of increased uncertainty in financial markets, an additional verification of entity positions in the futures market was conducted using Commitment of Traders reports published by the Commodity Futures Trading Commission for selected periods and currencies.

4. Analysis of correlation between currency indices and S&P 500

The summary of correlation coefficients between the S&P 500 index returns and the returns of major currency indices during the analyzed periods is presented in Table 2. This table also includes the weighted average of the correlation coefficients for the analyzed events, where the weights were determined by the number of weeks in each analyzed period. Additionally, the table provides the arithmetic means of the correlation coefficients for these events.

Table 2.

Summary of correlation coefficients of selected currency indices against the S&P500

Event	Analyzed weeks	Instruments	CHF_I	JPY_I	USD_I	AUD_I	EUR_I	GBP_I	CAD_I
Dotcom bubble	135	S&P 500	-0,21	0,00	0,12	0,32	-0,03	-0,02	0,26
Financial crisis 2007	74	S&P 500	-0,14	-0,57	-0,29	0,76	0,16	0,39	0,54
Eurozone crisis	8	S&P 500	-0,58	0,05	-0,20	0,77	0,53	0,19	0,96
US-China trade wars	14	S&P 500	-0,24	-0,76	0,14	0,66	-0,08	0,28	0,45
COVID-19 pandemic	6	S&P 500	-0,20	-0,58	-0,73	0,86	-0,33	0,82	0,47
Bear market in 2022	43	S&P 500	0,10	-0,24	-0,52	0,51	0,16	0,45	0,38
Weighted average for the analyzed events	237	S&P 500	-0,16	-0,24	-0,11	0,50	0,05	0,20	0,38
Arithmetic mean for the analyzed events		S&P 500	-0,21	-0,35	-0,25	0,64	0,07	0,35	0,50
Total	1118	S&P 500	-0,10	-0,30	-0,22	0,53	0,09	0,29	0,40

Source: own study based on data from stooq.pl.

The analysis of correlation coefficients between currency indices and the S&P 500 index during periods of heightened market volatility provides important insights into the role of these currencies as safe havens.

The Swiss Franc index consistently showed a negative correlation with the S&P 500 index during all analyzed periods. The correlation ranged from -0.14 during the 2007 financial crisis to -0.58 during the Eurozone crisis.

The Japanese Yen index displayed a slightly positive correlation (0.05) with the S&P 500 only during the Eurozone crisis. During the Dotcom bubble, the correlation was nearly zero. In other periods, it showed a strong negative correlation, exceeding -0.5.

US Dollar index was the least stable during periods of heightened uncertainty. In two cases, it showed a positive correlation with the S&P 500 (during the Dotcom bubble and the US-China trade wars). In other periods, it showed a negative correlation, with the most pronounced negative correlation occurring during the COVID-19 pandemic.

The other analyzed currencies, including the Australian Dollar (AUD), Euro (EUR), British Pound (GBP), and Canadian Dollar (CAD), all exhibited positive correlations with the S&P 500, both for the entire 21st century and during the periods of heightened uncertainty.

5. Analysis of the net position of selected groups of entities on the futures market using Commitment of Traders reports

For better understanding the behavior of selected investor groups analyzed in the Commitment of Traders (COT) reports, an additional examination of the actions of specific financial market entities was conducted. For each period, one currency relative to the U.S. dollar was chosen. The net positions of large speculators are represented in green, commercials in red, and small speculators in blue. In two cases where the dollar exhibited a positive correlation, the positions of currencies considered safe havens relative to the dollar were presented. In the remaining cases, currencies that achieved the highest positive correlation values were selected, allowing for clearer observation of prevailing trends.

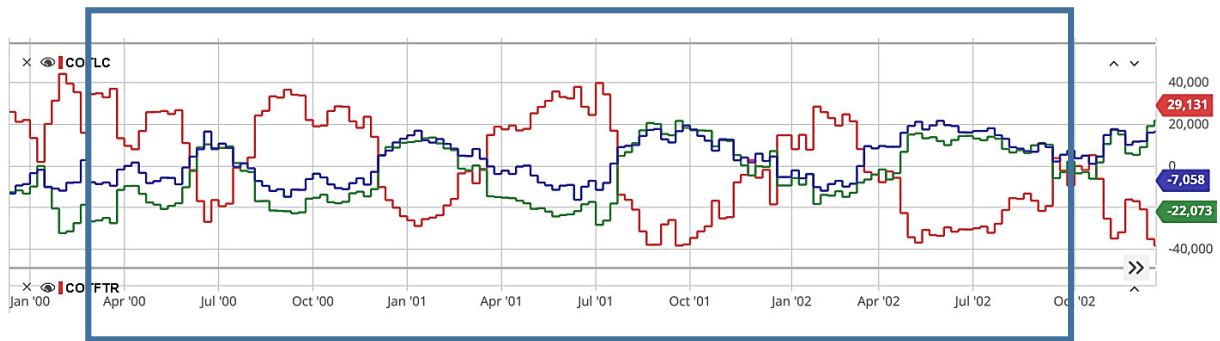


Figure 1. Net positions of various entities in the CHFUSD futures market during the period from January 2000 to December 2002.

Source: www.barchart.com, 11.08.2024.

According to Figure 1, it can be observed that from the onset of the decline, large speculators gradually reduced their short positions in the USD/CHF pair. Starting from July 2001, net positions began to stabilize above zero, indicating a predominance of long positions in CHF by large speculators. In this context, the changes in net positions are consistent with the analyzed correlation between the returns of the CHF index and the S&P 500.

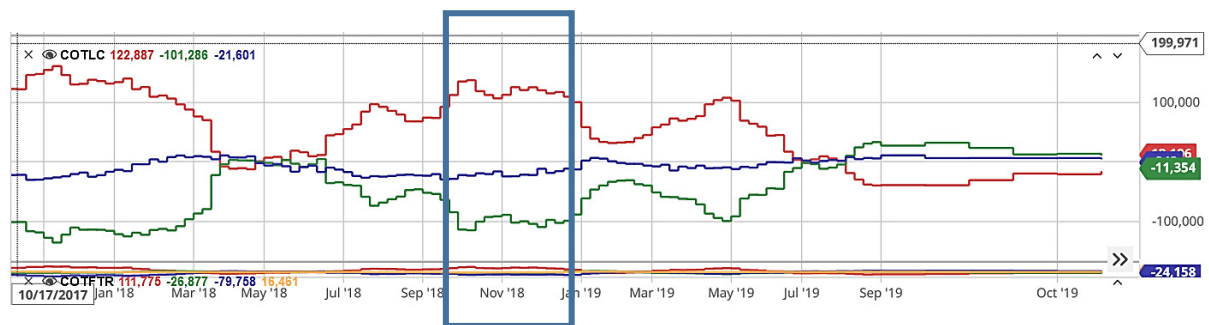


Figure 2. Net positions of various entities in the JPYUSD futures market during the period from November 2017 to October 2018.

Source: www.barchart.com, 11.08.2024.

In the case of the US-China trade wars period (Figure 2), despite the strong negative correlation between JPY and the S&P 500, no clear trends of large speculators reversing their short positions were observed during the analyzed period. In fact, such a reversal only occurred after the S&P 500 index reached its low point in December 2018. In this case, the changes in net positions can be considered neutral.

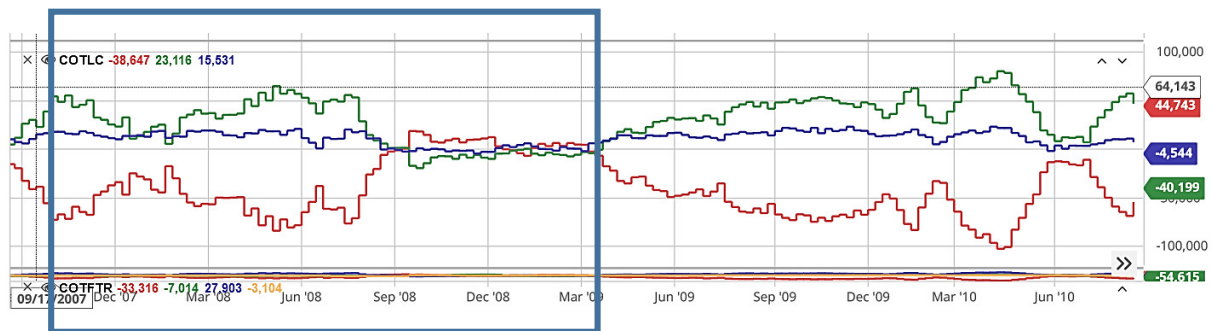


Figure 3. Net positions of various entities in the AUDUSD futures market during the period from September 2007 to October 2010.

Source: www.barchart.com, 11.08.2024.

During the 2007 financial crisis (Figure 3), the AUD exhibited the highest positive correlation coefficient with the S&P 500. It can be observed that large speculators initially reduced their positions at the onset of the crisis, only to rebuild a similar volume of net long positions by mid-2008. However, in September 2008, there was a notable reduction in long positions once again, leading to a stabilization of the net position with a balance between long and short position. In this case, the changes in net positions can be considered consistent with the analyzed correlation between the returns of the AUD index and the S&P 500.

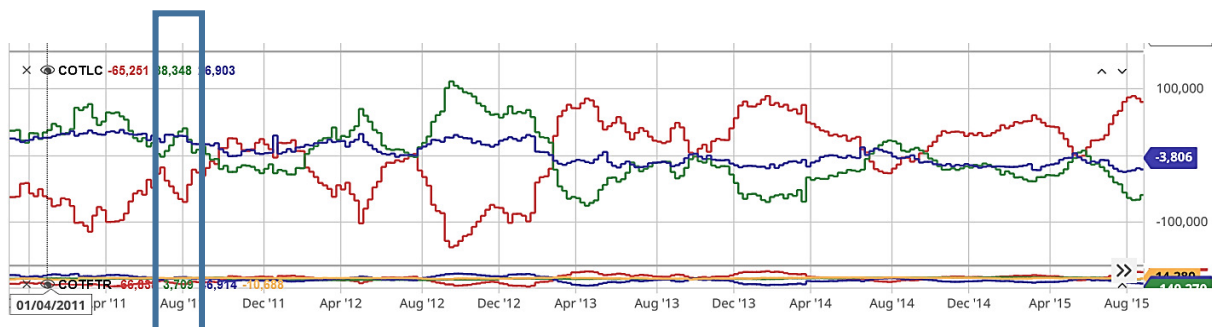


Figure 4. Net positions of various entities in the CADUSD futures market during the period from December 2011 to August 2015.

Source: www.barchart.com, 11.08.2024.

During the Eurozone crisis (Figure 4), when the correlation coefficient between the Canadian dollar index and the S&P 500 index was nearly 1, there was an initial tendency among large speculators to increase long positions during the early phase of the downturn. However, as the crisis progressed, these long positions were gradually reduced to levels seen before the analyzed period. In this case, the changes in net positions can be considered neutral.

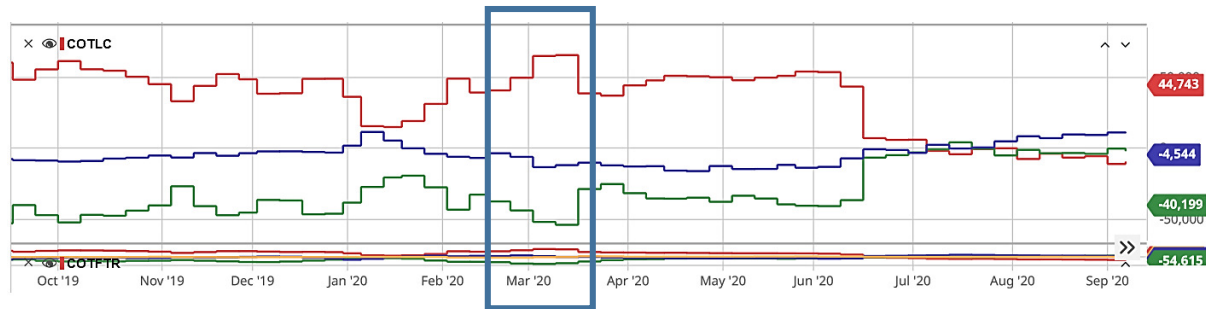


Figure 5. Net positions of various entities in the AUDUSD futures market during the period from September 2019- to October 2021.

Source: www.barchart.com, 11.08.2024.

During the COVID-19 pandemic (Figure 5.) period, despite a clearly positive correlation coefficient between the AUD index and the S&P 500 during the initial phase of declines, there was an observable increase in short positions on the AUD. In the final phase of the declines, however, short positions began to be reversed, and the scale of this reduction offset the earlier increase in short positions. Subsequently, the net position achieved did not significantly differ the levels observed before the onset of the market declines. In this case, the changes in net positions can be considered neutral.

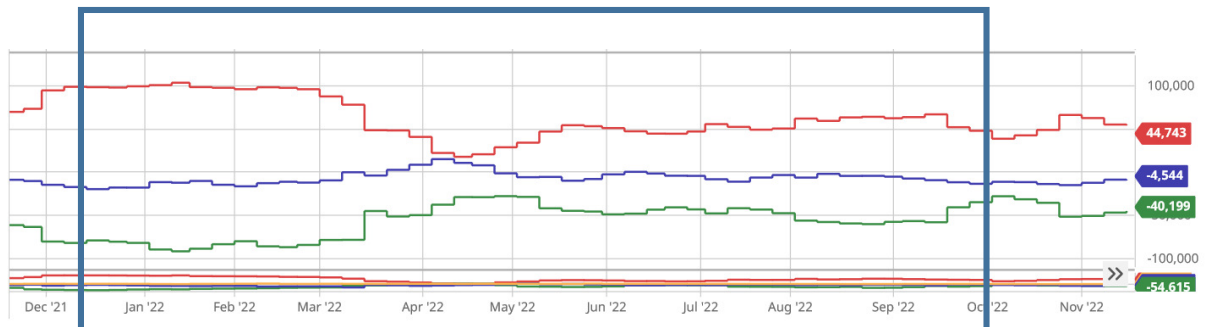


Figure 6. Net positions of various entities in the AUDUSD futures market during the period from December 2021 - to November 2022.

Source: www.barchart.com, 11.08.2024.

In the most recent bear market analyzed for the year 2022 (Figure 6) it is observed that large speculators reduced their short positions on AUDUSD for most of the period. This reveals a divergence relative to the calculated correlations between the AUD index and the S&P 500. In this case, the change in net positions appears inconsistent with the correlation analysis of returns.

6. Discussion

The results contained in the first part of the empirical analysis, where the Pearson linear correlation coefficients were calculated, can be summarized for individual currencies as follows:

Swiss Franc (CHF) - Both the weighted and arithmetic averages of the CHF's correlation with the S&P 500 during the analyzed periods were more negative than the average correlation over the entire period. This indicates that the Swiss Franc consistently exhibited a stronger negative correlation with the S&P 500 during times of heightened volatility, reinforcing its role as a reliable safe haven currency. The stability of this relationship across different crises suggests that CHF is a key asset for investors seeking protection in turbulent market conditions.

Japanese Yen (JPY) - The weighted average correlation for the analyzed events was less negative than for the entire 21st century, largely due to the near-zero correlation observed during the Dotcom bubble. However, the arithmetic average of -0.38 was notably more negative compared to the overall average for the entire period. This makes JPY the currency with the most strongly negative average correlations during periods of increased market uncertainty, despite some fluctuations. These results confirm the Yen's position as a robust safe haven, especially during significant financial stress.

US Dollar (USD) - The weighted average correlation during the analyzed periods was only slightly negative, primarily due to the positive correlation observed during the Dotcom bubble. The arithmetic average for these periods was somewhat more negative than the overall average for the 21st century, at -0.22. This suggests that while the USD played a role as a safe haven, its consistency was less reliable compared to the CHF and JPY.

Other Analyzed Currencies (EUR, GBP, AUD, CAD) - The Euro showed the weakest positive correlation with the S&P 500, with its weighted and arithmetic averages not exceeding 0.07. In three of the six analyzed periods, the Euro demonstrated a negative correlation, which may reflect its international significance and susceptibility to external influences during periods of instability. GBP, AUD, and CAD indices generally exhibited positive correlations with the S&P 500 during the analyzed periods, resulting in distinctly positive average correlations. Their arithmetic average correlation coefficients were higher for the analyzed periods than for the entire 21st century.

This positive correlation for GBP, AUD, and CAD indicates that these currencies were often sold off sharply alongside equity indices by investors during times of instability. In contrast, the lower correlations for CHF, JPY, USD, and EUR demonstrate that during stock market declines, demand for these currencies increased significantly as investors sought safety or moved to close carry trade positions. Other factors influencing currency strength appear to have diminished in importance during these periods.

This detailed analysis underscores the different roles of currencies during periods of financial instability, with CHF, JPY, and USD emerging as reliable safe havens, while the other currencies generally tracked equity market trends. Considering the arithmetic mean of the correlations with the S&P 500 index during periods of instability, as well as the frequency of not achieving negative correlations, it can be observed that the USD served as a safe haven to a lesser extent compared to the JPY and CHF.

When considering the arithmetic average for the analyzed periods, the correlation of USD, CHF and JPY during times of instability is negative and more pronounced than for the entire period under review. However, the weighted average correlation by the number of weeks for JPY and USD does not consistently confirm this relationship.

These results are in line with studies conducted by other scientists. Similar conclusions for the CHF and JPY were drawn by (Ranaldo, Soderlind, 2010) for the period 1993-2008. According to this study, these currencies fulfilled their safe haven role. Park (2023) conclusions are also consistent with the results in a more detailed dimension, confirming that during the 2007 crisis the JPY best fulfilled the safe haven criterion, while in the uncertainty of 2022 (Ukraine war), the USD performed better. Discrepancies can be found in the analysis by Cheema, Faff, and Szulczyk (2022) regarding the US dollar during the pandemic. In this study, where a regression analysis method was used, the USD only weakly met the criteria of a safe haven during the pandemic. However, in the case of the global financial crisis period and the analysis of the Swiss franc for both periods of instability examined, the conclusions from the analyses were consistent with the results obtained.

The second part of the empirical analysis, which involved examining the net positions of selected groups of entities on the futures market using Commitment of Traders reports, did not clearly confirm the conclusions from the first part of the analysis. In two instances, changes in the net positions of large speculators were consistent with the tendency to reallocate from risky assets or increase long positions in currencies considered safe havens. In three cases, the changes in the net positions of large speculators were neutral, with no significant changes observed at the end of the analyzed periods compared to their beginnings. In one case, the changes in net positions were inconsistent.

The findings are inconclusive, which may suggest that the analysis of futures market data is not fully representative and does not adequately capture market trends, or that the assumption large speculators accurately reflect market tendencies may be flawed. A deeper analysis of these relationships could provide valuable insights for a better interpretation of the data available in the COT reports.

In summary, the conclusions from the two studies can be seen as expanding previous analyses of safe haven currencies by providing a structured approach for the 21st century, while also examining other major currencies, adding a broader perspective to the analysis. By doing this, it also confirms that apart from the currencies considered in the past, no new currency (apart from the EUR) aspires to play the role of a safe haven. The practical implications

regarding the safe haven functions of CHF, JPY, and USD, as well as the behavior of other currencies during periods of instability, can be useful both in the active investment process and in mitigating currency exposure for enterprises and households.

7. Conclusions

The analysis conducted confirms the main research question affirmatively: the US Dollar (USD), Japanese Yen (JPY), and Swiss Franc (CHF) exhibit a negative correlation with the stock market during periods of uncertainty in the 21st century. The negative correlation for these currencies is stronger compared to other analyzed currencies.

The main limitation of the study was the restriction of correlation analyses to the S&P 500 index. As this index includes large global companies in the world's largest economy, it should reasonably reflect global trends.

Investor behavior, as reflected in the Commitments of Traders reports for selected currencies and periods, showed that changes in net positions of large speculators were inconclusive. Neutral changes predominated across most cases. Clear shifts consistent with the correlations between the analyzed currencies and the S&P 500 index were observed in only 2 out of the 6 cases. Additionally, in one instance, the direction of changes was contrary to expectations.

The presented analysis provides a foundation for further research, such as exploring whether there is also a nonlinear negative correlation for the studied currencies. It could also be valuable to complement the analysis with the return rates of currency indices during the examined periods or to include other currencies with lesser significance in global trade.

An interesting area of research could involve investigating whether the analyzed relationships might prove useful in specific investment strategies, such as contrarian or momentum strategies. Exploring these questions could offer deeper insights into the behavior of currencies during periods of market instability and their potential applications in financial strategies.

The main conclusions of the study certainly contribute to the current body of knowledge regarding the potential for hedging a currency portfolio in today's environment, allowing both businesses and individuals to reduce exposure to exchange rate fluctuations and stabilize their investment portfolios. It also offers a new perspective, indicating that analyzing the positions of selected entities in the futures markets may not always confirm capital flows into currencies considered safe havens or outflows from currencies deemed risky.

References

1. Admiral Markets (2024). *Bezpieczne przystanie na rynku*. Retrieved from: <https://admiralmarkets.com/pl/education/articles/fundamental-analysys/bezpieczne-przystanie-na-rynku>, 21.08.2024.
2. Anand, R., Madhogaria, S. (2012). Is gold a “safe-haven”? *An econometric analysis, Procedia Eco- nomics and Finance*, 1(12), pp. 24-33.
3. Baur, D., Lucey, B. (2010). Is Gold a Hedge or a Safe Haven? An Analysis of Stocks, Bonds and Gold. *The Financial Review*, vol. 45.
4. Baur, D., McDermott, T. (2010). Is gold a safe haven? International evidence. *Journal of Banking & Finance*, vol. 34.
5. Bouri, E., Molnar, P., Azzi, G., Roubaud, D., Hagfors, L. (2017). On the hedge and safe haven properties of Bitcoin: Is it really more than a diversifier? *Finance Research Letters*, vol. 20.
6. Brunnermeier, M. (2010). *Bubbles, liquidity, and the macroeconomy*. Cambridge: NBER Reporter Online.
7. Cheema, M.A., Faff, R., Szulczyk, K.R. (2022). The 2008 global financial crisis and COVID-19 pandemic: How safe are the safe haven assets? *International Review of Financial Analysis*, 83, 102316.
8. Ciner, C., Gurdgiev, C., Lucey, B.M. (2013). Hedges and safe havens: An examination of stocks, bonds, gold, oil and exchange rates. *International Review of Financial Analysis*, 29, 202-211.
9. González-Hermosillo, B., Hesse, H. (2009). Global Market Conditions and Systemic Risk. International Monetary Fund. *IMF Working Paper*.
10. Hood, M., Malik, F. (2013). Is Gold the Best Hedge and a Safe Haven Under Changing Stock Market Volatility. *Review of Financial Economics*.
11. Joy, M. (2011). Gold and the US dollar: Hedge or haven? *Finance Research Letters*, 8(3), 120-131.
12. Park, K. (2023). Safe haven currency behavior in crisis periods: The US dollar, the Japanese yen, and the Swiss franc. *Central and Eastern Europe in the Changing Business Environment*, 181-191.
13. Potrykus, M. (2015). Inwestycja w złoto – bezpieczna przystań, zabezpieczenie czy źródło dywersyfikacji dla polskiego inwestora. *Nauki o Finansach*, no. 3(24).
14. Przyłuska-Schmitt, J., Jegorow, D., Bučková, J. (2022). Investments in gold or cryptocurrencies? Safe haven during the COVID-19 pandemic. *Zeszyty Naukowe. Organizacja i Zarządzanie*, 158. Politechnika Śląska.
15. Rinaldo, A., Söderlind, P. (2009). Safe Haven Currencies. *Forthcoming in Review of Finance*.

16. Ranaldo, A., Söderlind, P. (2010). Safe haven currencies. *Review of finance*, 14(3), 385-407.
17. Ratner, M., Chiu, C. (2013). Hedging stock sector risk with credit default swaps. *International Review of Financial Analysis*.
18. Reboredo, J.C. (2013a). Is gold a hedge or safe haven against oil price movements? *Resources Policy*, 38(2), 130-137.
19. Reboredo, J.C. (2013b). Is gold a safe haven or a hedge for the US dollar? Implications for risk management. *Journal of Banking & Finance*, 37(8), 2665-2676.
20. Roache, S.K., Rossi, M. (2010). The effects of economic news on commodity prices. *The Quarterly Review of Economics and Finance*, 50(3), 377-385.

ANALYSIS OF THE ENERGY MIX IN POLAND AND THE EUROPEAN UNION IN TERMS OF RENEWABLE ENERGY PROSPECTS

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Purpose: The article aimed to understand the structure of the energy mix in EU countries, particularly in comparison with Poland, from 1990-2022.

Design/methodology/approach: The research was conducted on data from 27 EU countries between 1990 and 2022 using statistical methods with particular emphasis on analysis of the dynamics of phenomena and clustering.

Findings: Studies have confirmed a substantial increase in the share of renewable energy sources (RES) in the energy mix of the EU countries. A considerable increase was recorded in wind and solar energies. However, solid fuels still are in use in EU countries, particularly in countries whose economies are based on coal, including Poland.

Originality/value: The article's value is to view the development energy mix in Poland and the EU from a multidimensional analysis conducted in two separate time units. It allowed conclusions about the development of RES in Poland and the EU to be drawn.

Keywords: energy mix, renewable energy sources, electricity and derived heat production. cluster analysis.

Category of the paper: research paper.

1. Introduction

In recent years, responsibility for environmental protection has gained value and has become unquestionable. Worldwide changes, particularly concerning environmental issues, have forced, among other things, an adjustment in how energy sources should be used. Trends towards an increasing share of renewable energy sources (RES) in energy production have resulted in many separate and joint regulations in individual countries.

The evolution of the EU's emissions reduction policy dates back to the 1990s (Skjærseth, 2021; Jorge-Vazquez et al., 2024). One of the first climate policy instruments in the European Union was the mandatory EU Emissions Trading Scheme (2003). The main issues addressed were climate change, energy security and economic growth. The Lisbon Strategy (2000-2010) was also in place independently. In 2007, a target was set (compared to 1990 levels):

a 20% reduction in greenhouse gas emissions, a 20% increase in EU energy from renewable sources, and a 20% improvement in energy efficiency up to 2020. In October 2014, the Paris Agreement adopted a climate and energy policy framework for 2030, including a new national greenhouse gas reduction target of at least 40% compared to 1990 and a 27% increase in renewable energy consumption. Several regulations on emissions and climate change followed this. In fact, between 1990 and 2016, greenhouse gas emissions in the EU fell by more than 20%. Finally, the European Green Deal was launched in December 2019 (Skjærseth, 2021). And then, on 14 July 2021, the European Commission announced a legislative package on climate and energy - Fit for 55. The package is a set of relevant legislative proposals, subordinated to the EU's main climate target of reducing greenhouse gas emissions compared to 1990 levels by at least 55% by 2030 and making the EU climate-neutral by 2050 ("Fit for 55" 2023; *Regulation (EU) 2021/1119*, 2021). Essential aspects included minimising final energy consumption while increasing the share of renewable energy sources in the overall energy mix. As a result, EU members have been developing new legislation to accomplish.

In 2021, Poland issued a document entitled "Energy Policy of Poland until 2040" (PEP2040). The directions of PEP2040 include the optimal use of indigenous energy resources, the development of energy markets, the implementation of nuclear power, the development of renewable energy sources, and the improvement of the economy's energy efficiency (PEP2040, 2021). Also, after Russia's aggression in Ukraine, the Polish Minister of Climate and Environment issued assumptions for the PEP2040 update, in which the need for Poland's energy self-sufficiency further emphasised the importance of RES in diversifying the energy mix. According to the document, just about half of the electricity generated should come from renewable sources by 2040 (Ministry of Climate and Environment, 2022).

Many studies show that there has been a noticeable increase in the share of energy from renewable sources in recent years in European countries (Olczak, Matuszewska, Kryzia, 2020; Brodny, Tutak, Bindzár, 2021; Sobczyk, Sobczyk, 2021; Bórawski et al., 2022; Jonek-Kowalska, Kurdelski, 2022; Mularczyk, Zdonek, 2022; Wolniak, Skotnicka-Zasadzień, 2022, 2023; Zdonek et al., 2022; Brodny, Tutak, 2023; Jonek-Kowalska, 2023; Mularczyk, 2023; Simionescu, Rădulescu, Cifuentes-Faura, 2023; Hassan et al., 2024; Hysa, Mularczyk, 2024; Stec et al., 2024) as well as all over the world (Azarpour et al., 2022; Lau et al., 2022; Qaiser, 2022; Triguero-Ruiz, Avila-Cano, Trujillo Aranda, 2023; Yolcan, 2023, 2023; Hassan et al., 2024; Tiwari et al., 2024; Zhang, Wang, Liu, 2024). Nonetheless, although the energy mix has diversified significantly in recent years, the use of fossil fuels in the EU is still a significant source of direct CO₂ emissions (Paraschiv, Paraschiv, 2020).

Research conducted by (Miciuła et al., 2020) confirms that the demand for energy resources among EU countries is vast. These countries consume 16% of the energy produced in the world and primarily have to import it. Therefore, considering the peculiarities of each country's energy mix, there is a need to measure and ensure the sustainable development of all EU members and energy security based on the rational and efficient use of energy resources.

Increasing the share of renewable energy sources in the energy mix also contributes to energy security by reducing dependence on imported energy carriers (Sobczyk, Sobczyk, 2021). In particular, in the fact of the Russian conflict in Ukraine, in the face of the energy crisis (caused by rising electricity prices), energy conservation, security and reducing dependence on imports of fossil fuels, especially coal, and an accelerated transition to nuclear and renewable energy, have become a necessity for EU countries (Brodny, Tutak, 2023; Hille, 2023; Koval et al., 2023; Kartal et al., 2024).

Some EU countries have made significant progress in the energy transition (e.g., Sweden and Denmark). While others face more significant energy transition challenges related to the decarbonisation of their energy sector (e.g., Poland) (Jonek-Kowalska, 2022; Kaczmarek, Kolegowicz, Szymła, 2022; Koval et al., 2023; Jonek-Kowalska, Grebski, 2024; Jonek-Kowalska, Rupacz, 2024; Jorge-Vazquez et al., 2024; Manowska et al., 2024). However, the share of coal in Poland's energy mix decreased primarily after 2015 compared to previous years (Rybak et al., 2024). And there has been an unquestionable rise in the use of RES in our country in the last decade (Olczak, Matuszewska, Kryzia, 2020; Kulpa et al., 2022; Mularczyk, Zdonek, 2022; Wolniak, Skotnicka-Zasadzień, 2022, 2023; Zdonek et al., 2022; Jonek-Kowalska, 2023; Mularczyk, 2023; Hysa, Mularczyk, 2024; Jonek-Kowalska, Rupacz, 2024; Świdyńska, 2024).

According to the literature analysis, no studies were reported comprehensively on the structure of the energy mix and the structure of renewable energy sources used for energy production in Poland against the background of the European Union countries for the entire period since the beginning of the foundation of the EU in 1990. Therefore, the article aims to learn about the structure of the energy mix in EU countries, particularly in comparison with Poland, from 1990-2022. Three main research questions were posed, each of which was further developed regarding Poland to achieve this aim:

RQ1: How did the share of individual resources in electricity and heat production in the EU change between 1990 and 2022?

RQ1a: How did the share of individual resources in electricity and heat production in Poland change between 1990 and 2022?

RQ2: How has the structure of renewable energy sources in the energy mix in the EU changed from 1990 to 2022?

RQ2a: How has the structure of renewable energy sources in the energy mix in Poland changed from 1990 to 2022?

RQ3: What groups could EU countries be divided into regarding the energy mix in 1990 and 2022?

RQ3a: How did Poland compare to other EU countries regarding energy mix in 1990 and 2022?

2. Materials and Methods

The data was collected from the open data platform Eurostat (*Eurostat*, 2024). It was concerned for electricity and derived heat production by fuel type in European Union countries from 1990 to 2022, assessed in thousand tonnes of oil equivalent (ktoe). Initially, data was assembled by distinguishing fuel types: solid fossil fuels, oil and petroleum products, natural gas, nuclear heat, and renewables with biofuels. Then, the structure of renewables was analysed. It included hydro, geothermal, wind, solar, primary solid biofuels, biogases, and renewable municipal waste. Statistical methods with particular emphasis on analysis of the dynamics of phenomena and clustering were used. Calculations were performed in a spreadsheet and the R Studio environment.

3. Results

The research results were presented in the following order: firstly, the general structure of electricity sources and derived heat in the European Union and Poland separately, and secondly, more accurate results concerning renewable energy sources in the same scheme. Finally, in the third part of this chapter, all 27 countries currently members of the EU were clustered for the beginning and end of the period under review two times: in terms of energy mix and renewable energy sources structure.

3.1. The energy in the European Union and Poland

To answer the first research question – RQ1 (How did the share of individual resources in electricity and heat production in the EU change between 1990 and 2022), the European Union's energy structure was initially analysed. Figure 1 presents a column chart showing the change in the structure of energy and derived heat sources between 1990 and 2022 combined in all 27 countries currently members of the European Union.

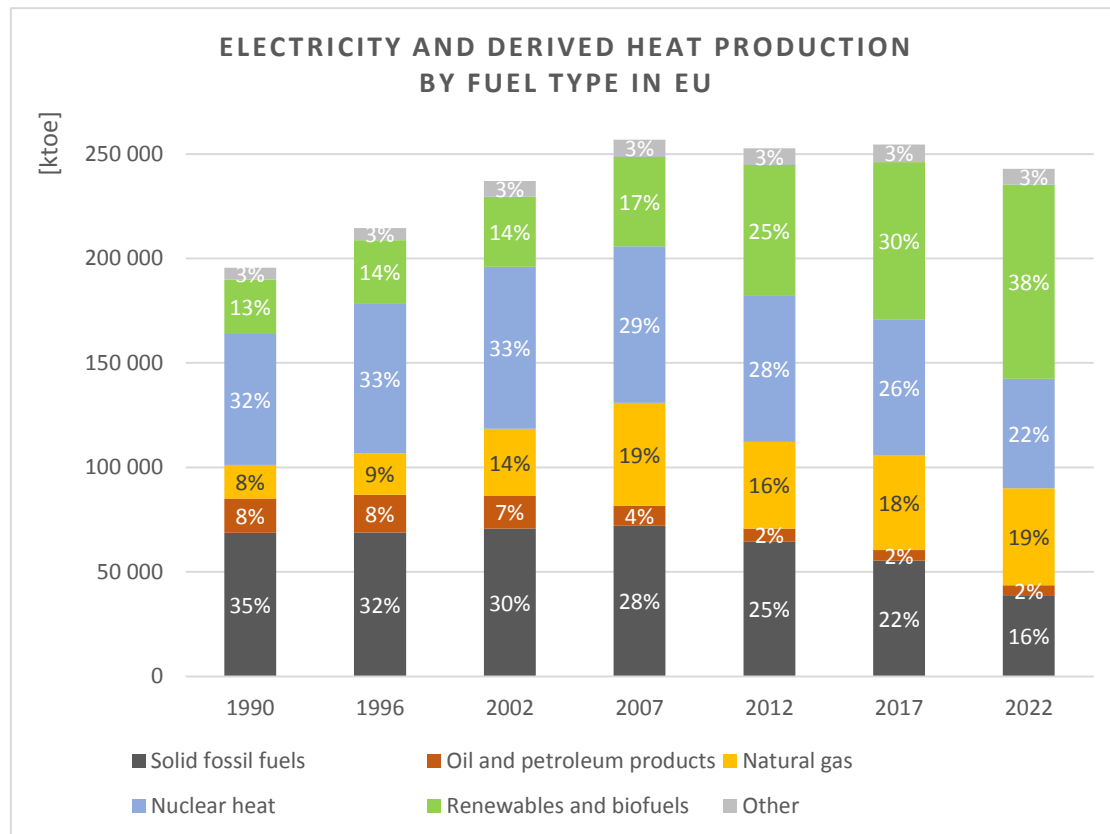


Figure 1. Electricity and derived heat production by fuel type in the European Union.

Source: own calculations based on data from (Eurostat, 2024).

Table 1, in turn, displays calculations of the dynamics of change of these shares in 2022 compared to 1990 (and 2007 for comparison) in total in the countries studied.

Table 1

The change in EU production and share of electricity and derived heat by fuel type

Source	1990		2022		Increase/decrease in 2022			
	Total [ktoe]	Share of total	Total [ktoe]	Share of total	compared to 1990		compared to 2007	
					Total	Share	Total	Share
Solid fossil fuels	68 792.43	35%	38 799.54	16%	-44%	-55%	-46%	-43%
Oil and petroleum products	16 296.05	8%	4 793.07	2%	-73%	-76%	-49%	-46%
Natural gas	16 127.52	8%	46 507.02	19%	135%	107%	-6%	-0,3%
Nuclear heat	62 692.52	32%	52 386.54	22%	-16%	-33%	-30%	-26%
Renewables and biofuels	25 958.61	13%	92 844.18	38%	258%	188%	118%	130%

Source: own calculations based on data from (Eurostat, 2024).

The total energy and derived heat production was in 1990 the level of 195,637 and in 2022: 242,843 [ktoe]. It represents an overall increase of 24%. However, a graph shows that after an initial apparent growth trend, it breaks down around 2007. It remains more stable or slightly declining instead. In 2007, energy production reached 256,903 [ktoe]. In these conditions, there was a visible decrease in fossil fuel share of about half (54%), from 35% to 16%. There were also decreases in shares of oil and petroleum products (76%, from 8% to 2%) and nuclear heat (33%: from 32% to 22%). In contrast, the share of natural gas increased from 18%

over the period under review, reaching a maximum around 2007 (19%; 49,325 [ktoe]), with the share in 2022 being 107% higher than in 1990. However, the share of renewable energy sources showed the most intense growth. It changed from 13% to 38%, representing a 188% share growth, with a total product amount increase of 258% (from 25,959 to 92,844 [ktoe]).

In turn, a similar analysis was conducted for Poland to compare and answer research question RQ1a (How did the share of individual resources in electricity and heat production in Poland between 1990 and 2022). Figure 2 presents a graph showing the structures of energy sources and derived heat between 1990 and 2022 in Poland. Nuclear heat was not included at this time because it did not exist in Poland during the analysed period.

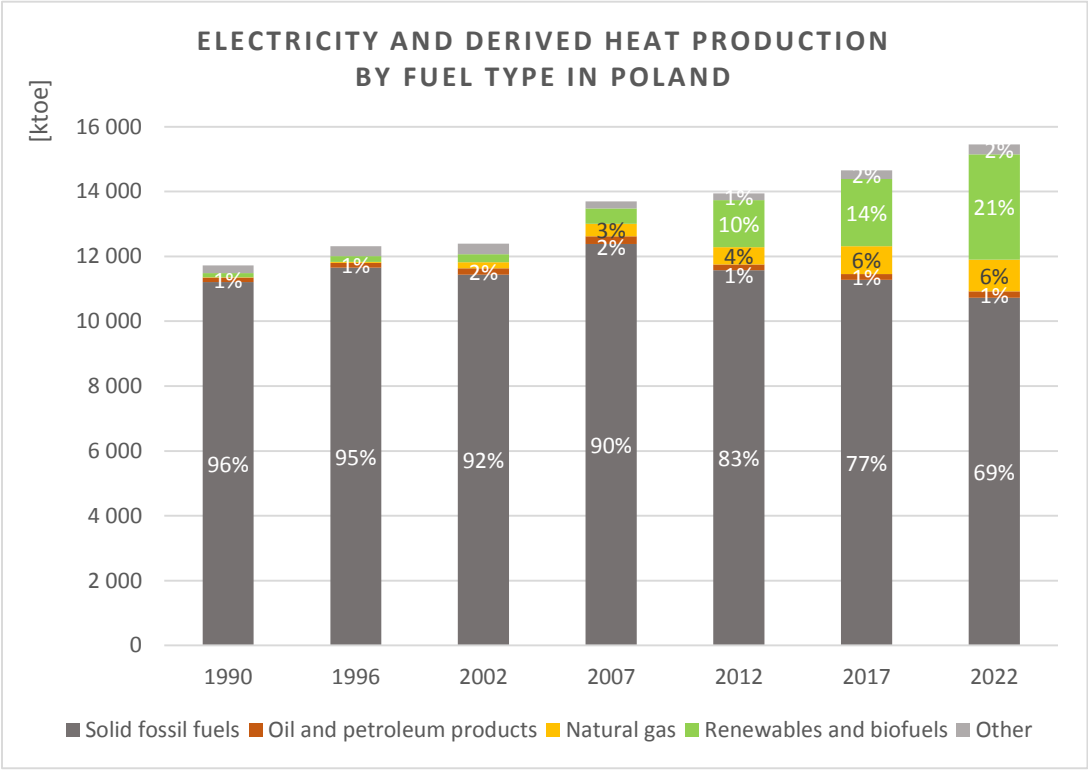


Figure 2. Electricity and derived heat production by fuel type in Poland.

Source: own calculations based on data from (Eurostat, 2024).

Analogously, Table 2 shows calculations of the dynamics of change in these shares in 2022 compared to 1990 and 2007 in Poland.

Table 2*The change in Poland's production and share of electricity and derived heat by fuel type*

Source	1990		2022		Increase/decrease in 2022			
	Total [ktoe]	Share of total	Total [ktoe]	Share of total	compared to 1990		compared to 2007	
					Total	Share	Total	Share
Solid fossil fuels	11 209.03	96%	10 724.61	69%	-4%	-27%	-13%	-23%
Oil and petroleum products	135.00	1.2%	202.29	1,3%	33%	6%	-16%	-25%
Natural gas	10.75	0.1%	976.34	6,3%	3415%	2700%	153%	125%
Renewables and biofuels	128.51	1%	3 240.63	21%	2422%	1812%	594%	515%

Source: own calculations based on data from (Eurostat, 2024).

As for Poland, a significant change could be observed in how electricity and derived heat were produced. While 96% of the source of this energy was solid fuels, by 2022, almost a third of the power already came from other sources. Although the amount of energy from fossil fuels only slightly dropped (from 11,209 to 10,725 ktoe, which stands for 4%), its share in the energy mix significantly decreased – by 27% (from 96% to 69%). Also, in 2022, corresponding to 1990, slight growth in oil and petroleum product usage could be noticed (6%). However, it is worth noticing that the usage of this source was even higher in 2007 and then dropped. A visible increase was noted in natural gas use. This source's share has been successfully developing from almost nothing (0.1%; nearly 11 [ktoe]) to 6.3% (976 [ktoe]), meaning a 2,700% growth. However, the most substantial improvement regarding renewables and biofuels during the analysed period was noticed. The energy production from these sources initially of about 129 [ktoe] in 1990 amounted to 3,241 [ktoe] in 2022, as its share grew from 1% to 21%. It stood for a 1,812% growth in share and 2,422% in total.

3.2. The energy from renewables in the European Union and Poland

As the most significant increases in Poland and the European Union have been from the perspective of renewable energy sources, a more in-depth analysis of this phenomenon was the next step. It was addressed by research questions RQ2 and RQ2a. First, to answer research question RQ2 (How has the structure of renewable energy sources in the energy mix in the EU changed from 1990 to 2022), the production of renewable electricity and derived heat in 27 European Union countries was analysed by isolating individual renewable energy sources. Figure 3 presents renewable energy production divided into seven sub-categories according to source: hydro, geothermal, wind, solar (it included both photovoltaics and solar-thermal), primary solid biofuels, biogases, and renewable municipal waste. Likewise, Table 3 shows the total values and shares of the analysed RES.

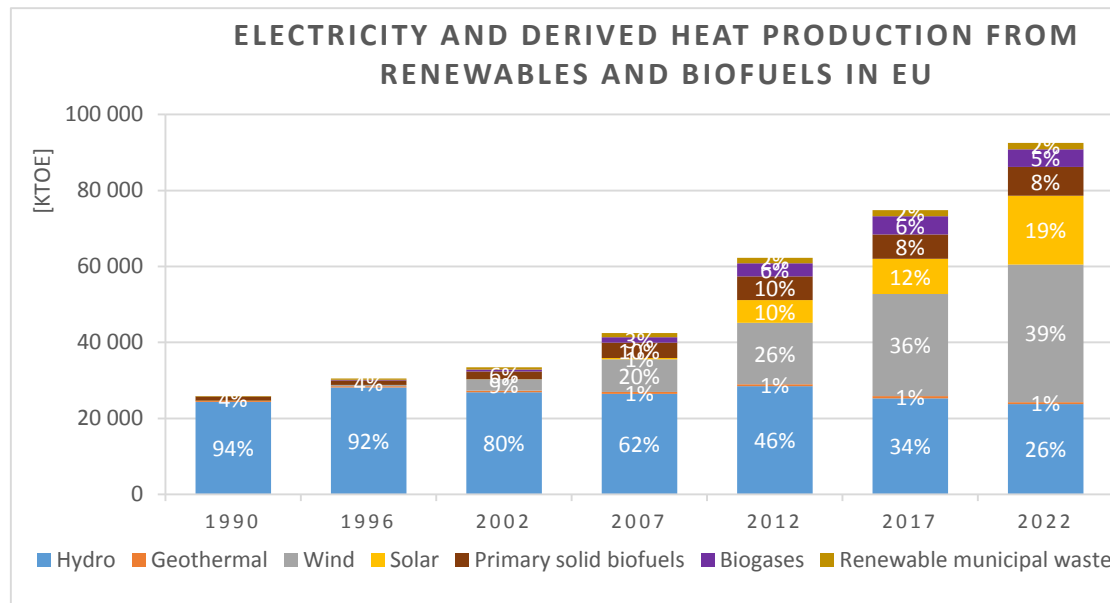


Figure 3. Electricity and derived heat production from renewables in the European Union.

Source: own calculations based on data from (Eurostat, 2024).

Table 3.

The change in EU production and share of electricity and derived heat from renewables

Source	1990		2022		Increase/decrease in 2022			
	Total [ktoe]	Share of total	Total [ktoe]	Share of total	compared to 1990		compared to 2012	
					Total	Share	Total	Share
Hydro	24 388.94	94%	23 752.14	26%	-3%	-73%	-17%	-44%
Geothermal	277.39	1.1%	552.69	0,6%	69%	-44%	10%	-25%
Wind	66.15	0.3%	36 226.74	39%	9,501%	3,059%	125%	52%
Solar	1.37	0.01%	18 078.18	19%	1,324,309%	370,196%	200%	102%
Primary solid biofuels	939.41	4%	7 569.62	8%	706%	125%	22%	-18%
Biogases	39.49	0.2%	4 669.88	5%	11,727%	3,207%	34%	-10%
Renewable municipal waste	202.67	1%	1 661.72	2%	720%	129%	16%	-22%

Source: own calculations based on data from (Eurostat, 2024).

The bar chart confirmed the increase in energy production from renewable energy sources. It changed from 25,959 to 92,844 [ktoe], which meant an increase of 258%. The primary energy renewable source in 1990 was water. At that time, hydropower covered 94% of RES production. But, in 2022, it already accounted for only 26%, which meant a 73% decrease in share. Nonetheless, this source showed some stability, as the total energy produced from it only dropped by 3%. Namely, in 1990, it was 24,389; in 2022, it was slightly less, 23,752 [ktoe]. Such a significant decline in share was caused by an even greater increase in the importance of RES in the overall energy mix. Similar conclusions could be drawn about geothermal energy, although its share was not as significant. Production from this source more than doubled in the period under review (69%: from 277 to 553 [ktoe]); however, when looking at its percentage share of total RES, it fell by as much as 44% (from 1.1% to 0.6%) and then has a marginal share of the total RES for now.

On the contrary, since the beginning of the 21st century, the unquestionable boom in the EU has been in wind power and, since around 2012, solar sources. Wind power increased from nearly 66 [Ktoe] in 1990 (which was about 0.3% of the share in renewables) up to 36 227 [ktoe] (39% of the share). It showed the most rapid growth among EU renewable sources, as seen in the chart above. However, solar sources have also been developing rapidly in the last decade. In 1990, the amount of energy from solar sources was only about 1.4 [ktoe], which accounted for almost nothing (approximately 0.01%); in 2022, the same source gave 18 078 [ktoe] instead (19% of the share). Compared only to 2012, by 2022, solar energy has increased by 102% in share and about 200% in total. Also, significant developments in such sources as primary solid biofuels, biogases, and renewable municipal waste can be seen. However, even in 2022, their share did not exceed 10%.

An equivalent analysis was conducted for Poland to compare results and answer research question RQ2a (How has the structure of renewable energy sources in the energy mix in Poland changed from 1990 to 2022). In Figure 4, the bar chart presents renewable energy production divided into six sub-categories according to source: hydro, wind, solar (photovoltaics and solar-thermal), primary solid biofuels, biogases, and renewable municipal waste. Geothermal was not applicable in Poland during the analysed period. Table 4 also shows the total values and shares of the analysed RES.

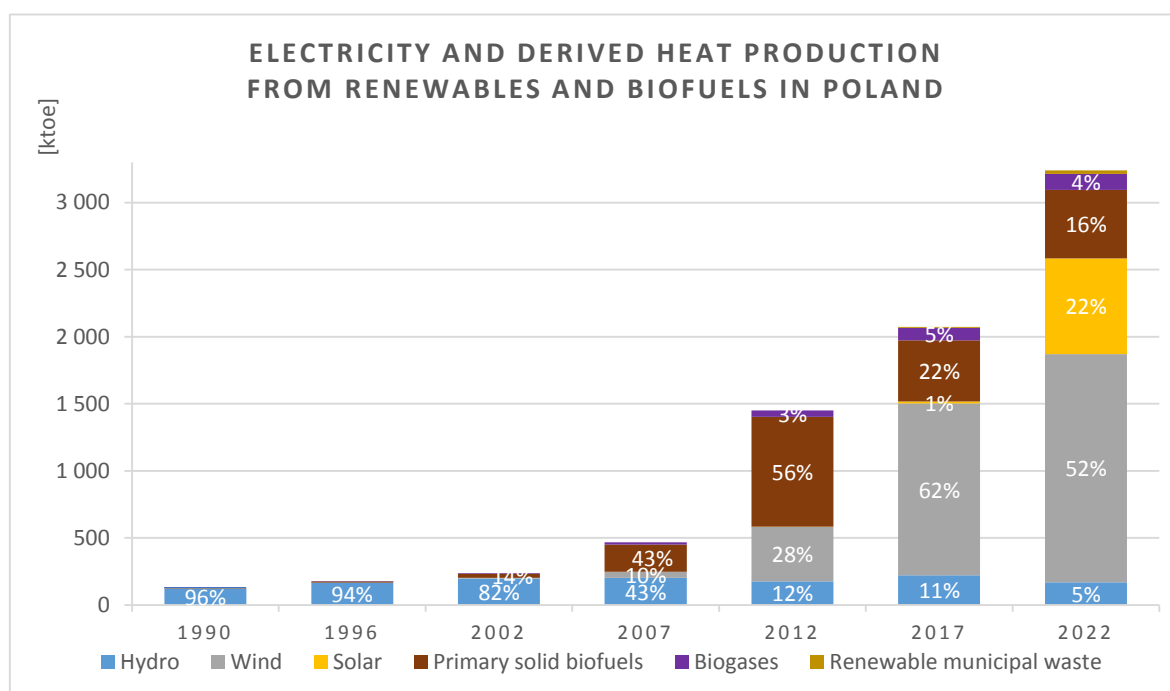


Figure 4. Electricity and derived heat production from renewables in Poland.

Source: own calculations based on data from (Eurostat, 2024).

Table 4*The change in Poland's production and share of electricity and derived heat from renewables*

Source	1990		2022		Increase/decrease in 2022			
	Total [ktoe]	Share of total	Total [ktoe]	Share of total	compared to 1990		compared to 2012	
					Total	Share	Total	Share
Hydro	123.78	96%	169.23	5%	37%	-95%	-3%	-57%
Wind	-	-	1 700.73	52%	-	-	317%	87%
Solar	-	-	714.50	22%	-	-	728 985%	326 419%
Primary solid biofuels	4.73	4%	510.24	16%	10 690%	328%	-38%	-72%
Biogases	-	-	119.88	4%	-	-	147%	10%
Renewable municipal waste	-	-	25.94	1%	-	-	-	-

Source: own calculations based on data from (*Eurostat*, 2024).

Analysing Poland's energy mix, it appeared that renewable energy sources and their importance were discovered in the first or even second decade of the 21st century. It was undoubtedly related to the political and regime changes in the last decade of the 20th century. In 1990, only two renewable energy sources were visible: hydro and primary solid biofuels. Nevertheless, energy from water accounted for as much as 96% of the total RES used. Although hydro energy's share dropped significantly (to 5%), its production increased indeed (from 124 to 169 [ktoe], which indicated a 37% rise). Also, primary solid biofuels expanded from nearly 5 to above 510 [ktoe], representing a 16% share in 2022. In their place, wind had the largest share of RES in 2022 (52%), followed closely by solar sources (22%). Both of these sources were virtually non-existent in 1990. Additionally, in 2022, trace amounts (not exceeding 5%) of biogas and renewable municipal waste could be seen among RES.

3.3. Cluster analysis

European countries differ in many ways, such as geographical location, possession of natural resources, and economic status. These differences have an impact on the structure of the energy mix. Therefore, in the further part of the analysis, all EU countries were clustered to group those with similar characteristics. The purpose was to answer the last two research questions: RQ3 (What groups could EU countries be divided into regarding the energy mix in 1990 and 2022) and RQ3a (How did Poland compare to other EU countries regarding energy mix in 1990 and 2022).

Energy mix in 1990

Figure 5 presents the clustering result for all 27 countries currently belonging to the EU due to their structure of individual sources in the energy mix in 1990. The calculations were carried out for Euclidean distances using the Ward method.

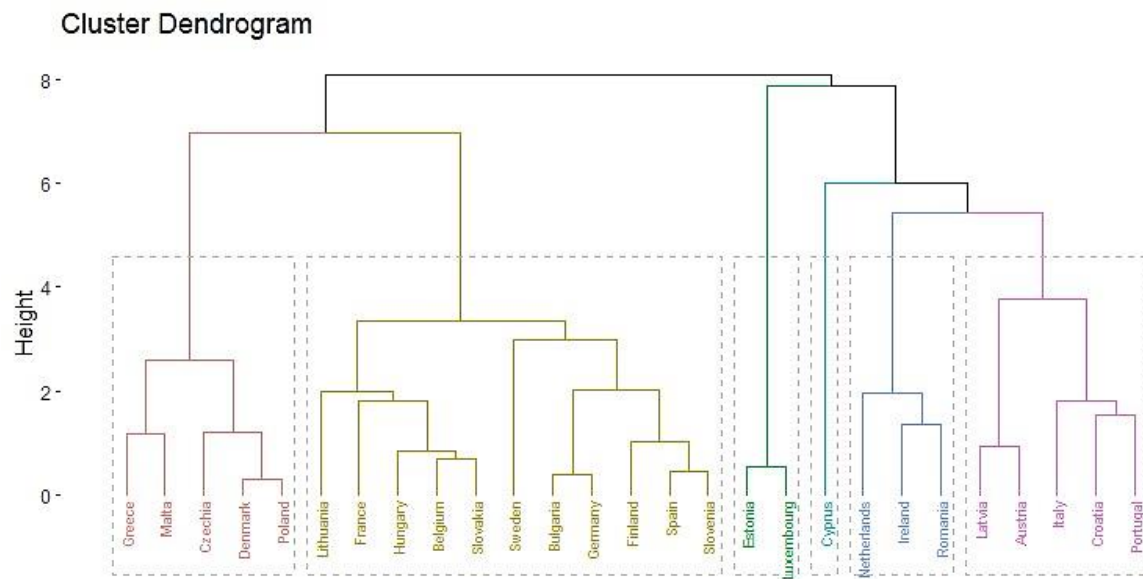


Figure 5. Results of Cluster Analysis for energy mix in 1990.

Source: own calculations.

It seemed best to divide the countries surveyed into six groups. The membership of each group is shown in Table 5.

Table 5.
Countries in each cluster for 1990

Cluster	Country
1	<u>Belgium</u> , <u>Bulgaria</u> , <u>Germany</u> , <u>Spain</u> , <u>France</u> , <u>Lithuania</u> , <u>Hungary</u> , <u>Slovenia</u> , <u>Slovakia</u> , <u>Finland</u> , <u>Sweden</u>
2	<u>Czechia</u> , <u>Denmark</u> , <u>Greece</u> , <u>Malta</u> , <u>Poland</u>
3	<u>Estonia</u> , <u>Luxembourg</u>
4	<u>Ireland</u> , <u>Netherlands</u> , <u>Romania</u>
5	<u>Croatia</u> , <u>Italy</u> , <u>Latvia</u> , <u>Austria</u> , <u>Portugal</u>
6	<u>Cyprus</u>

Note: the underlined countries were already members of the EU at that time.

Source: own calculations based on data from (Eurostat, 2024).

It can be noted that the grouping in 1990 did not depend on whether a given country was in the EU at that time. The rationale for this partition is shown in Table 6, which places the average shares of each type of source in each group.

Table 6.
The average share of individual energy sources in clusters for 1990

Cluster	1	2	3	4	5	6
Average production [ktoe]	11 976	4 488	798	4 322	5 347	170
Solid fossil fuels	26%	78%	0%	40%	13%	0%
Natural gas	7%	1%	4%	38%	15%	0%
Oil and petroleum products	5%	14%	5%	11%	24%	100%
Renewables and biofuels	14%	2%	3%	8%	46%	0%
Nuclear heat	46%	4%	0%	2%	0%	0%
Other	2%	1%	89%	2%	2%	0%

Source: own calculations based on data from (Eurostat, 2024).

In the first cluster, there were eleven countries with the highest energy production volume (on average, 11 976 [ktoe]). At that time, the largest energy source in these countries was nuclear heat (46%), followed by solid fossil fuels (26%). Renewables and biofuels reached, on average, a 14% share. The second-highest energy production had, on average, five countries in the fifth group. They relied visibly on renewables and biofuels (46%). The second source was oil and petroleum (24%). Poland and four other countries were placed in the second group, which was placed in the third position regarding production size. Still, the average energy production in this group was more than half less than that of the first group. This group's primary energy source was solid fossil fuels (78%), followed by oil and petroleum products (14%). The four countries in the fourth cluster did not have much lower average energy production than the second cluster. The fourth group's primary energy source was solid fossil fuels (40%) and natural gas (38%), followed by oil and petroleum products but only at 11%. The third group consisted of only two countries that did not rely on any leading energy sources. At the same time, they had the second-lowest average production (the fifth position). Interestingly, solid fossil fuels were not used in this group at all. Finally, the last cluster that produced the least amount of energy consisted of only Cyprus, which used only oil and petroleum as energy sources. Cyprus was in a separate group due to the unique, quite different conditions of this country, which is actually an island, from the rest of the EU members. However, care was taken not to exclude any of the 27 countries from the analysis as long as possible.

Thus, the first group of countries can be described as a nuclear-based group, the second – based on solid fossil fuels, the fourth – based on solid fossil fuels combined with natural gas, and the fifth – based on renewable energy sources. In addition, the third group was based on other sources.

Energy mix in 2022

To see how changes in the energy mix have evolved over 32 years, the same analysis was carried out for the latest year of the study period: 2022. In Figure 6, the cluster dendrogram for the 2022 year was presented. This time, the countries were also divided into six groups, as presented in Table 7.

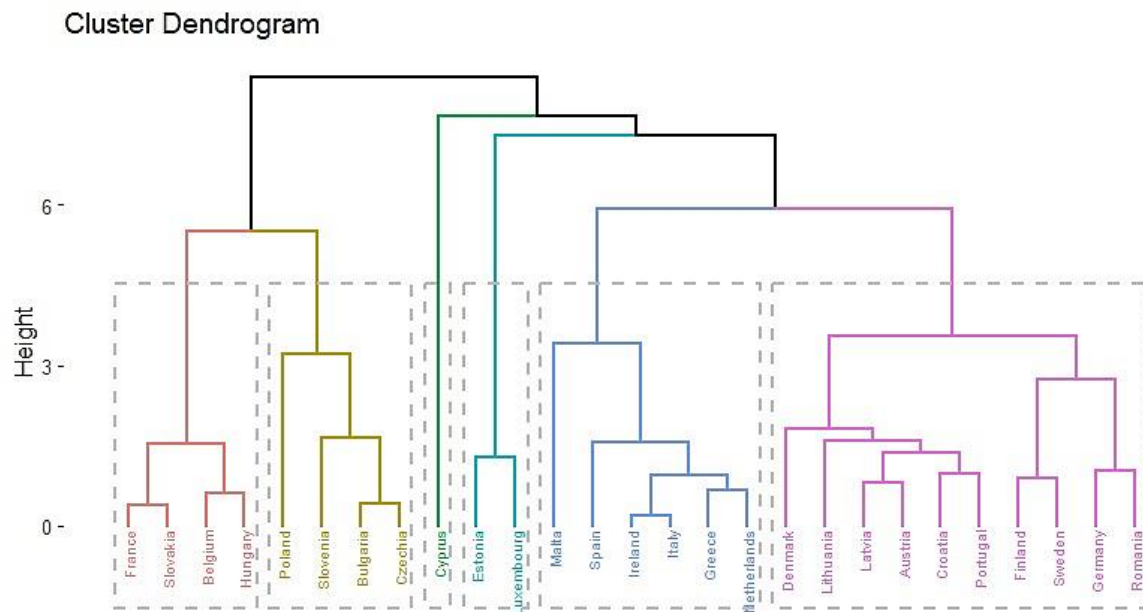


Figure 6. Results of Cluster Analysis for energy mix in 2022.

Source: own calculations.

Table 7.

Countries in each cluster for 2022

Cluster	Country
1	Belgium, France, Hungary, Slovakia
2	Bulgaria, Czechia, Poland, Slovenia
3	Denmark, Germany, Croatia, Latvia, Lithuania, Austria, Portugal, Romania, Finland, Sweden
4	Estonia, Luxembourg
5	Ireland, Greece, Spain, Italy, Malta, Netherlands
6	Cyprus

Source: own calculations.

Table 8 displays the average total production and shares in the clusters.

Table 8.

The average share of individual energy sources in clusters for 2022

Cluster	1	2	3	4	5	6
Average production [ktoe]	13 614	7 066	9 104	480	11 278	453
Solid fossil fuels	4%	45%	8%	0%	7%	0%
Natural gas	16%	5%	15%	3%	48%	0%
Oil and petroleum products	1%	1%	2%	0%	4%	83%
Renewables and biofuels	23%	21%	62%	39%	35%	17%
Nuclear heat	53%	28%	9%	0%	4%	0%
Other	3%	2%	5%	59%	2%	0%

Source: own calculations based on data from (Eurostat, 2024).

The countries with the most significant energy production on average were placed in the first cluster. There were four countries in this group. Their primary energy source was nuclear heat (53%). However, it was followed by renewables and biofuels this time, which accounted for an average of almost a quarter of the mix (23%). The second-largest production level had four countries in the fifth cluster. These countries relied mainly on nuclear energy (48%) but also more than a third on renewables (35%). The third rank obtained ten countries of the third cluster. After all, renewables were this group's first energy source (62%). They were followed by natural gas but only at 15%. Four countries in the second cluster, including Poland, had the fourth-highest energy production on average. Fossil solid fuels still had the largest share in this group (45%). However, it can be noted that the shares of nuclear power (28%) and RES (21%) were not so small. The last two by production volume were specific groups. The fourth cluster consisted of only two countries, Luxembourg and Estonia, as the third cluster in 1990. As before, their primary energy sources were quite different from those of the other countries (59%). However, it is worth noting that their share of RES increased noticeably to 39%. And sixth place was Cyprus, with oil and petroleum products being the basic energy source (83%). However, RES took second place in its energy mix (17%).

Thus, the first group contained nuclear-fueled countries; the second group consisted of solid fossil fuels-based countries. The third cluster was based on RES, the fourth on other sources, and the fifth on natural gas. It can be said that in the third group of countries, renewable energy sources were the most developed. Still, the fact is that in each of these groups, they were at a reasonably high level – over 20%. Its share increased unquestionably.

To conclude the analysis, the countries were again grouped separately for the years 1990 and 2022 in terms of the structure of the RES.

RES structure in 1990

Although by 1990, RES were not yet developed, an attempt was made to perform a cluster analysis of EU countries nonetheless. As three countries (Estonia, Cyprus, and Malta) had no renewable energy sources at all at that time, they were excluded before the procedure was started to allow for calculations. Figure 7 presents the outcome of the analysis.

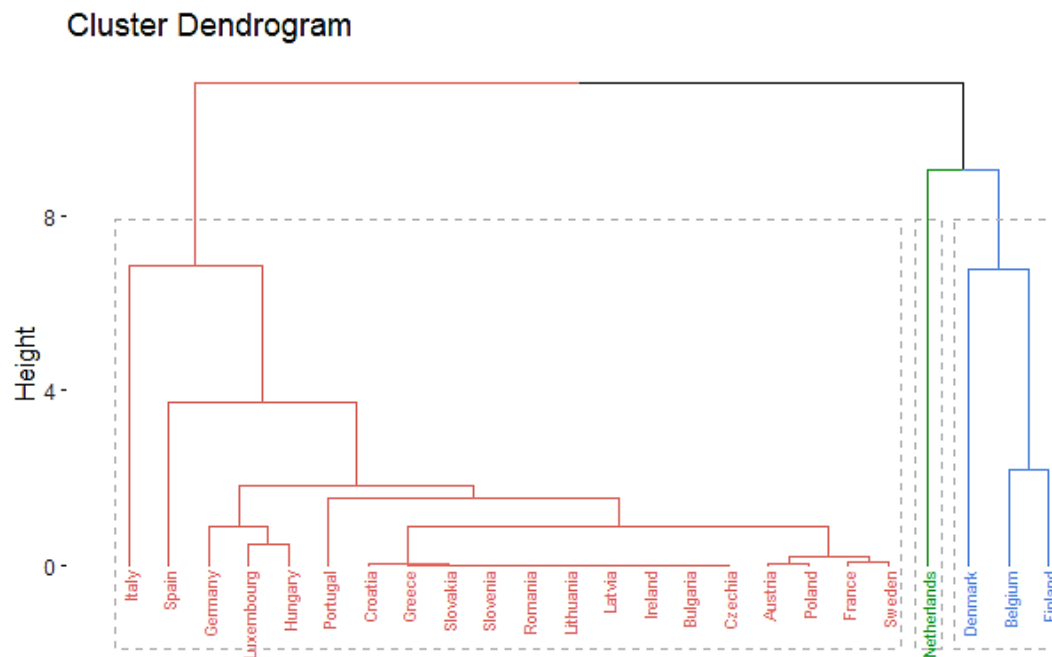


Figure 7. Results of Cluster Analysis for RES Structure in 1990.

Source: own calculations.

This time, the countries were divided into three clusters. The fourth group consists of Estonia, Cyprus, and Malta, not to omit any item. The clusters are listed in Table 9.

Table 9.

Countries in each cluster for RES in 1990

Cluster	Country
1	Belgium, Denmark, Finland
2	Bulgaria, Czechia, Germany, Ireland, Greece, Spain, France, Croatia, Italy, Latvia, Lithuania, Luxembourg, Hungary, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Sweden
3	Netherlands
4	<i>The group without RES (excluded): Estonia, Cyprus, Malta</i>

Note: the underlined countries were already members of the EU at that time.

Source: own calculations.

Table 10 presents the average total production from RES and shares of seven sub-categories in the clusters.

Table 10.

The average share of individual RES in clusters for 1990

Cluster	1	2	3	4
Average production [ktoe]	499	1 220	69.3	0
Hydro	40%	97%	11%	-
Geothermal	-	0.5%	-	-
Wind	25%	0.03%	7%	-
Solar	0.001%	0.003%	0.05%	-
Primary solid biofuels	23%	1.1%	4.3%	-
Biogases	2%	0.1%	11%	-
Renewable municipal waste	10%	1.6%	67%	-

Source: own calculations based on data from (Eurostat, 2024).

As many as 20 countries from the second cluster produced the most significant average volume of energy from RES. At the same time, its source was almost only hydro (97%). In the first cluster, with more than two times lower average production level, there were only three countries. Their RES structure consisted of hydropower (40%), wind power (25%), and primary solid biofuels (23%). The Netherlands was isolated as the third cluster with the lowest and most scarce production. It used then renewable municipal waste at most (67%). Biogases and hydropower were at 11%. As said before, the fourth group contained three countries without energy from RES.

Thus, the first cluster's countries relied mainly on hydropower combined with wind and primary solid biofuels, and the second cluster relied almost entirely on hydropower. Solar energy was almost not used at that time.

RES structure in 2022

In Figure 8, cluster analysis results regarding 2022 are displayed. This time, all the countries were divided into three groups, listed in Table 11.

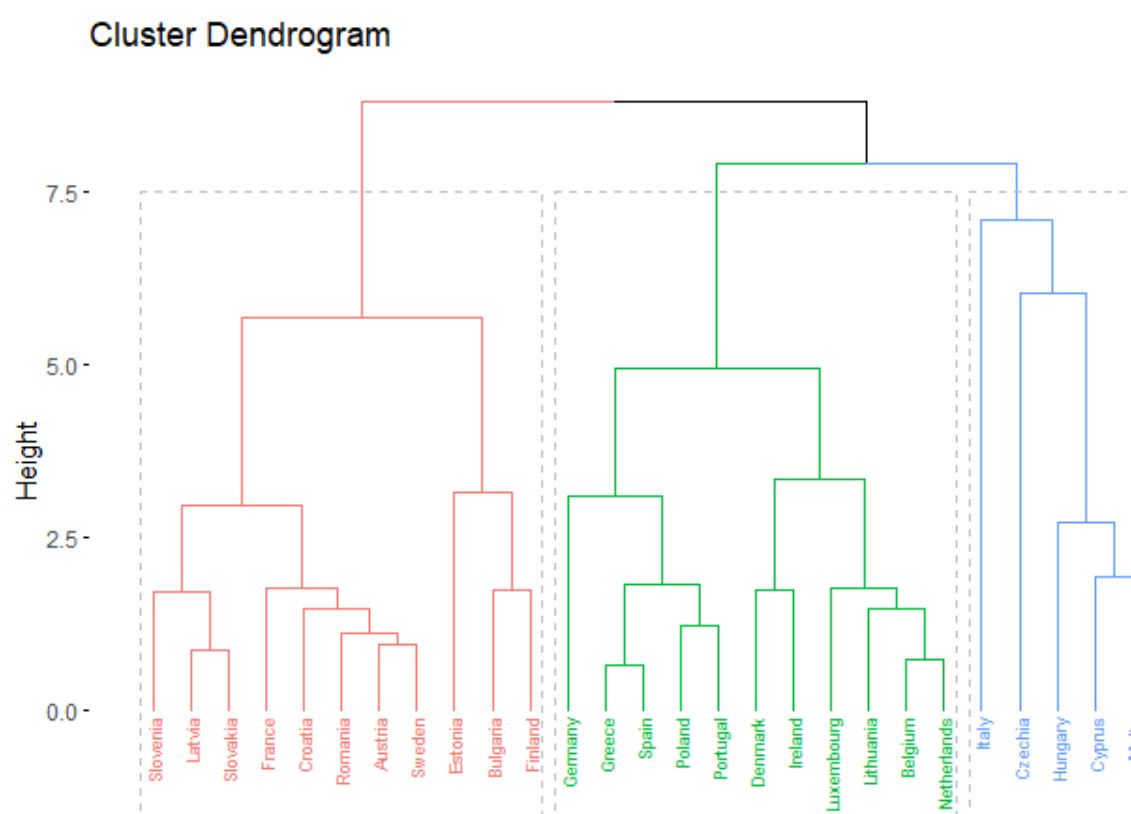


Figure 8. Results of Cluster Analysis for RES Structure in 2022.

Source: own calculations.

Table 11.*Countries in each cluster for RES in 2022*

Cluster	Country
1	Belgium, Denmark, Germany, Ireland, Greece, Spain, Lithuania, Luxembourg, Netherlands, Poland, Portugal
2	Bulgaria, Estonia, France, Croatia, Latvia, Austria, Romania, Slovenia, Slovakia, Finland, Sweden
3	Czechia, Italy, Cyprus, Hungary, Malta

Source: own calculations.

Table 12 presents the average total production and shares in the clusters.

Table 12.*The average share of individual RES in clusters for 2022*

Cluster	1	2	3
Average production [ktoe]	4 535	2 967	2 065
Hydro	9%	52%	10%
Geothermal	0.1%	0.1%	1%
Wind	53%	19%	12%
Solar	21%	10%	56%
Primary solid biofuels	11%	16%	10%
Biogases	4%	2%	9%
Renewable municipal waste	3%	1%	1%

Source: own calculations based on data from (Eurostat, 2024).

The highest level of electricity and heat derived from RES had eleven countries placed in the first cluster, including Poland. In these countries, over half of the output from RES was wind power (53%). It was followed by solar energy (21%). Hydro was also at the level of 11%. Eleven other countries of cluster two ranked second in energy production. Water was there the most important renewable energy source (52%). In 19%, it was also the wind; at 16%, it was the primary solid biofuel. The group with the comparatively lowest production from RES was cluster three, containing five countries. As much as 56% of this production came from solar energy. 12% was provided by wind, and 10% each came from hydropower and primary solid biofuels.

Thus, the first group relied mainly on wind power, the second on hydropower and the third on solar energy.

4. Discussion and summary

The analysis concluded that there has been a significant increase in the share of renewable energy sources in EU countries in recent years, confirming numerous previous studies documented in the literature. When observing the changes that have taken place in the structure of the energy mix from 1990 to 2022, one can see a rather significant decline in the percentage use of fossil fuels while the share of renewable energy sources has flourished. It has changed from 25,959 to 92,844 [ktoe] (258%), and in the energy produced share from 13% to 38%

(188% rise). Poland, too, has seen a significant increase in RES participation in recent years, confirming the results of earlier studies for example (Mularczyk, Zdonek, 2022; Wolniak, Skotnicka-Zasadzień, 2022, 2023; Zdonek et al., 2022; Świdyńska, 2024). At the same time, the consumption of fossil fuels has decreased, confirming studies that confirmed research (Rybak et al., 2024). However, they are still the dominant energy source (their share was about 70% in 2022), which is related to the long and complicated decarbonisation process of the hitherto coal-based economy, as previously described by (Jonek-Kowalska, 2022; Kaczmarek, Kolegowicz, Szymła, 2022; Jorge-Vazquez et al., 2024).

The results of the cluster analysis also confirmed those conclusions. In 1990, there were 6 groups of countries. In as many as two, fossil fuels dominated the energy mix (for solid fossil fuels and oil and petroleum products together, on average, from 51-92%): a total of eight countries. In these two clusters, renewables share was from 2 to 8%. One country relied exclusively on oil and petroleum products with no RES at all in its energy mix. Eleven countries were dominated by nuclear energy (46%) and supported by fossil fuels (31%), with renewables at 14%. Two countries produced energy from different sources (89%), with RES at 3%. In contrast, RES was the basis of energy production (46%) in only five countries, which also used all fossil fuels at 37%. This pattern has changed significantly in 2022. Countries were also divided into six groups. However, in most of them, RES had at least 21% (except Cyprus alone, with 17% of renewables and 87% of oil and petroleum products share). RES was also at least a second-dominant energy source in five of six clusters. As many as eleven countries relied on renewables at 62% on average. Only in one cluster, consisting of four countries (including Poland), fossil fuels dominated (46%). Besides, except for Cyprus, fossil fuels were at 0 to 11%, which was quite an impressive change.

Upon closer examination of the RES structure, a rapid increase in some sources was apparent. In the EU, the primary energy renewable source in 1990 was hydropower, which covered 94% of production from RES. After thirty-three years of not changing in terms of volume, it became only 26%. Other RES, such as wind, solar, and others, appeared during this period. Wind energy gained the largest share in 2022 (39%), followed by solar (19%). Primary solid biofuels (8%) were in fourth place in participation. In Poland, similarly, the initial level of hydro has hardly changed in terms of the value of energy produced from it or has even increased. However, its share of the total RES mix fell from 96 to 5%. That was again due to the appearance of other RES sources and their rapid development. The largest share in 2022 had wind (52%), followed by solar (22%). It confirmed the research of (Wolniak, Skotnicka-Zasadzień, 2022, 2023), among others. Primary solid biofuels accounted for as much as 16%.

Also, cluster analysis shed more light on the situation. In 1990, almost all countries relied on hydropower (except the Netherlands, relying on renewable municipal waste). However, three countries also had wind and primary solid biofuels at a reasonably high share level. Solar energy was practically not in use. In 2022, on the other hand, three groups of EU countries could be distinguished. The first group relied mainly on wind power, the second

on hydropower, and the third on solar energy. At the same time, the shares were more than 50% each time. Poland was in the group relying mainly on hydropower.

Studies have confirmed a significant increase in the share of RES in the energy mix of the countries now members of the European Union. RES sources themselves have also developed quantitatively, changing their structure. A substantial increase was recorded in wind and solar energies. However, solid fuels still exist in EU countries, although in a noticeably smaller share. In particular, countries whose economies are based on coal, including Poland, continue to rely on them as the primary energy source, even though they have visibly reduced their share in the mix. However, the unquestionable increase in RES is evidence of a good direction of their development.

References

1. Azarpour, A., Mohammadzadeh, O., Rezaei, N., Zendehboudi, S. (2022). Current status and future prospects of renewable and sustainable energy in North America: Progress and challenges. *Energy Conversion and Management*, 269, p. 115945. Available at: <https://doi.org/10.1016/j.enconman.2022.115945>.
2. Bórawski, P., Wyszomierski, R., Bėldycka-Bórawska, A., Mickiewicz, B., Kalinowska, B., Dunn, J.W., Rokicki, T. (2022). Development of Renewable Energy Sources in the European Union in the Context of Sustainable Development Policy. *Energies*, 15(4), p. 1545. Available at: <https://doi.org/10.3390/en15041545>.
3. Brodny, J., Tutak, M. (2023). Assessing the energy security of European Union countries from two perspectives – A new integrated approach based on MCDM methods. *Applied Energy*, 347, p. 121443. Available at: <https://doi.org/10.1016/j.apenergy.2023.121443>.
4. Brodny, J., Tutak, M., Bindzár, P. (2021). Assessing the Level of Renewable Energy Development in the European Union Member States. A 10-Year Perspective. *Energies*, 14(13), p. 3765. Available at: <https://doi.org/10.3390/en14133765>.
5. Eurostat (2024). Available at: <https://ec.europa.eu/eurostat/en/>, 2 October 2024.
6. Fit for 55 (2023). Consilium. Available at: <https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55/>, 15 October 2024.
7. Hassan, Q., Viktor, P.J., Al-Musawi, T., Mahmood, A.B., Algburi, S., Alzoubi, H.M., Khudhair Al-Jiboory, A., Zuhair Sameen, A., Salman, H.M., Jaszczur, M. (2024). The renewable energy role in the global energy Transformations. *Renewable Energy Focus*, 48, p. 100545. Available at: <https://doi.org/10.1016/j.ref.2024.100545>.
8. Hille, E. (2023). Europe's energy crisis: Are geopolitical risks in source countries of fossil fuels accelerating the transition to renewable energy? *Energy Economics*, 127, p. 107061. Available at: <https://doi.org/10.1016/j.eneco.2023.107061>.

9. Hysa, B., Mularczyk, A. (2024). PESTEL Analysis of the Photovoltaic Market in Poland—A Systematic Review of Opportunities and Threats. *Resources*, 13(10), p. 136. Available at: <https://doi.org/10.3390/resources13100136>.
10. 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*, 77, p. 102701. Available at: <https://doi.org/10.1016/j.resourpol.2022.102701>.
11. Jonek-Kowalska, I. (2023). Motives for the Use of Photovoltaic Installations in Poland against the Background of the Share of Solar Energy in the Structure of Energy Resources in the Developing Economies of Central and Eastern Europe. *Resources*, 12(8), p. 88. Available at: <https://doi.org/10.3390/resources12080088>.
12. Jonek-Kowalska, I., Grebski, W. (2024). Comparative Analysis of Domestic Production and Import of Hard Coal in Poland: Conclusions for Energy Policy and Competitiveness. *Energies*, 17(20), p. 5157. Available at: <https://doi.org/10.3390/en17205157>.
13. Jonek-Kowalska, I., Kurdelski, T. (2022). *The usage of renewable energy sources by countries in the Visegrád Group. Diagnosis and environmental effects*.
14. Jonek-Kowalska, I., Rupacz, S. (2024). Transformation of Energy Resources in the Visegrad Group: Strategies, Results, and Climate Effectiveness. *Resources*, 13(5), p. 64. Available at: <https://doi.org/10.3390/resources13050064>.
15. Jorge-Vazquez, J., Kaczmarek, J., Knop, L., Kolegowicz, K., Nájuez Alonso, S.L., Szymła, W. (2024). Energy transition in Poland and Spain against changes in the EU energy and climate policy. *Journal of Cleaner Production*, 468, p. 143018. Available at: <https://doi.org/10.1016/j.jclepro.2024.143018>.
16. Kaczmarek, J., Kolegowicz, K., Szymła, W. (2022). Restructuring of the Coal Mining Industry and the Challenges of Energy Transition in Poland (1990-2020). *Energies*, 15(10), p. 3518. Available at: <https://doi.org/10.3390/en15103518>.
17. Kartal, M.T., Pata, U.K., Erdogan, S., Destek, M.A. (2024). Facing the challenge of alternative energy sources: The scenario of European Union countries based on economic and environmental analysis. *Gondwana Research*, 128, pp. 127-140. Available at: <https://doi.org/10.1016/j.gr.2023.10.019>.
18. Koval, V., Khaustova, V., Lippolis, S., Ilyash, O., Salashenko, T., Olczak, P. (2023) 'Fundamental Shifts in the EU's Electric Power Sector Development: LMDI Decomposition Analysis. *Energies*, 16(14), p. 5478. Available at: <https://doi.org/10.3390/en16145478>.
19. Kulpa, J., Olczak, P., Stecula, K., Sołtysik, M. (2022). The Impact of RES Development in Poland on the Change of the Energy Generation Profile and Reduction of CO₂ Emissions. *Applied Sciences*, 12(21), p. 11064. Available at: <https://doi.org/10.3390/app122111064>.
20. Lau, H.C., Zhang, K., Bokka, H.K., Ramakrishna, S. (2022). A Review of the Status of Fossil and Renewable Energies in Southeast Asia and Its Implications on the

- Decarbonization of ASEAN. *Energies*, 15(6), p. 2152. Available at: <https://doi.org/10.3390/en15062152>.
21. Manowska, A., Bluszcz, A., Chomiak-Orsa, I., Wowra, R. (2024). Towards Energy Transformation: A Case Study of EU Countries. *Energies*, 17(7), p. 1778. Available at: <https://doi.org/10.3390/en17071778>.
22. Ministry of Climate and Environment (2022). *Assumptions for the March 2022 update of Poland's Energy Policy until 2040*, Ministerstwo Klimatu i Środowiska. Available at: <https://www.gov.pl/web/klimat/zalozenia-do-aktualizacji-polityki-energetycznej-polski-do-2040-r>, 2 October 2024.
23. Mularczyk, A. (2023). Development of renewable energy use in Polish industry compared to European countries. *Scientific Papers of Silesian University of Technology. Organization and Management Series*, 185, pp. 303-313. Available at: <https://doi.org/10.29119/1641-3466.2023.185.17>.
24. Mularczyk, A., Zdonek, I. (2022). Development of solar energy in Poland in the context of European countries. *Scientific Papers of Silesian University of Technology. Organization and Management Series*, 161, pp. 171-186. Available at: <https://doi.org/10.29119/1641-3466.2022.161.12>.
25. Olczak, P., Matuszewska, D., Kryzia, D. (2020). "Mój Prąd" as an example of the photovoltaic one off grant program in Poland. *Polityka Energetyczna – Energy Policy Journal*, 23(2), pp. 123-138. Available at: <https://doi.org/10.33223/epj/122482>.
26. Paraschiv, S., Paraschiv, L.S. (2020). Trends of carbon dioxide (CO₂) emissions from fossil fuels combustion (coal, gas and oil) in the EU member states from 1960 to 2018. *Energy Reports*, 6, pp. 237-242. Available at: <https://doi.org/10.1016/j.egy.2020.11.116>.
27. PEP2040 (2021) *Energy Policy of Poland until 2040*. Available at: <https://www.gov.pl/web/ia/polityka-energetyczna-polski-do-2040-r-pep2040>, 2 October 2024.
28. Qaiser, I. (2022). A comparison of renewable and sustainable energy sector of the South Asian countries: An application of SWOT methodology. *Renewable Energy*, 181, pp. 417-425. Available at: <https://doi.org/10.1016/j.renene.2021.09.066>.
29. Regulation (EU) 2021/1119 (2021). *OJ L*. Available at: <http://data.europa.eu/eli/reg/2021/1119/oj/eng>, 15 October 2024.
30. Rybak, Aurelia, Rybak, Aleksandra, Joostberens, J., Pielot, J., Toś, P. (2024). Analysis of the Impact of Clean Coal Technologies on the Share of Coal in Poland's Energy Mix. *Energies*, 17(6), p. 1394. Available at: <https://doi.org/10.3390/en17061394>.
31. Simionescu, M., Rădulescu, M., Cifuentes-Faura, J. (2023). Renewable Energy Consumption-Growth Nexus in European Countries: A Sectoral Approach. *Evaluation Review*, 47(2), pp. 287-319. Available at: <https://doi.org/10.1177/0193841X221125982>.
32. Skjærseth, J.B. (2021). Towards a European Green Deal: The evolution of EU climate and energy policy mixes. *International Environmental Agreements: Politics, Law and Economics*, 21(1), pp. 25-41. Available at: <https://doi.org/10.1007/s10784-021-09529-4>.

33. Sobczyk, W., Sobczyk, E.J. (2021). Varying the Energy Mix in the EU-28 and in Poland as a Step towards Sustainable Development. *Energies*, 14(5), p. 1502. Available at: <https://doi.org/10.3390/en14051502>.
34. Stec, M., Grzebyk, M., Caputa, W., Hejdukova, P. (2024). Levels of Renewable Energy Use in Selected European Union Countries – Statistical Assessment of Changes and Prospects for Development. *Comparative Economic Research. Central and Eastern Europe*, 27(3), pp. 117-140. Available at: <https://doi.org/10.18778/1508-2008.27.24>.
35. Świdczyńska, N. (2024). Renewable energy sources in Poland in 2014-2023 and the perspective of their development until 2030. A contribution to the discussion. *Olsztyn Economic Journal*, 19(1), pp. 31-44.
36. Tiwari, S., Shahzad, U., Alofaysan, H., Walsh, S.T., Kumari, P. (2024). How do renewable energy, energy innovation and climate change shape the energy transition in USA? Unraveling the role of green finance development. *Energy Economics*, 140, p. 107947. Available at: <https://doi.org/10.1016/j.eneco.2024.107947>.
37. Triguero-Ruiz, F., Avila-Cano, A., Trujillo Aranda, F. (2023). Measuring the diversification of energy sources: The energy mix. *Renewable Energy*, 216, p. 119096. Available at: <https://doi.org/10.1016/j.renene.2023.119096>.
38. Wolniak, R., Skotnicka-Zasadzień, B. (2022). Development of Photovoltaic Energy in EU Countries as an Alternative to Fossil Fuels. *Energies*, 15(2), p. 662. Available at: <https://doi.org/10.3390/en15020662>.
39. Wolniak, R., Skotnicka-Zasadzień, B. (2023). Development of Wind Energy in EU Countries as an Alternative Resource to Fossil Fuels in the Years 2016-2022. *Resources*, 12(8), p. 96. Available at: <https://doi.org/10.3390/resources12080096>.
40. Yolcan, O.O. (2023). World energy outlook and state of renewable energy: 10-Year evaluation. *Innovation and Green Development*, 2(4), p. 100070. Available at: <https://doi.org/10.1016/j.igd.2023.100070>.
41. Zdonek, I., Tokarski, S., Mularczyk, A., Turek, M. (2022). Evaluation of the Program Subsidizing Prosumer Photovoltaic Sources in Poland. *Energies*, 15(3), p. 846. Available at: <https://doi.org/10.3390/en15030846>.
42. Zhang, G., Wang, J., Liu, Y. (2024). Energy transition in China: Is there a role for climate policy uncertainty? *Journal of Environmental Management*, 370, p. 122814. Available at: <https://doi.org/10.1016/j.jenvman.2024.122814>.

GREEN DEAL AS ONE OF THE DETERMINANTS OF ENERGY POVERTY

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Purpose: The aim is to investigate whether the obligations of the European Green Deal have an impact on energy poverty in Poland.

Design/methodology/approach: The paper seeks to indicate whether the decarbonisation, renewable energy and energy efficiency commitments of the European Green Deal (EGD) have an impact on the scale of energy poverty. The paper uses two research methods. The first was a diagnostic survey method to determine whether households perceive climate issues as an important part of their well-being. The second is regression analysis to assess the impact of climate factors on the scale of energy poverty.

Findings: The results of the study indicated that, in the long term, energy poverty is influenced by macroeconomic stability of households, RES production and energy efficiency, while in the short term, since the introduction of the Green Deal rules, macroeconomic stability has proved to be the strongest influence.

Research limitations/implications: Unfortunately, there is a lack of long-term data on energy poverty as measured by the indicators recommended by the European Commission, which makes long-term analyses impossible.

Practical implications: The European Green Deal was implemented only a few years ago, so its long-term effects will take a few years to develop. For now, we can only analyse the short-term effects.

Social implications: The legislation does not distinguish between fuel poverty and energy poverty and, in addition, does not cover the full, including social, effects of energy poverty.

Originality/value: To the author's knowledge, this article is the first to analyse energy poverty not only in terms of energy prices, but also taking into account the climate dimension. So far, only the availability of energy on the grid or the financial possibilities for energy consumption have been analysed. This article also draws attention to the issues of access to clean energy and decarbonisation, understood as access to an environment with ever lower CO₂ emissions. This has practical implications for both households and industry.

Keywords: energy poverty, European Green Deal, decarbonisation, Poland.

Category of the paper: research paper.

1. Introduction

The European Green Deal (EGD) is a set of policy initiatives and regulations that set the European Union's climate goals for 2050 (European Commission, 2024a). According to it, the aim is to achieve climate neutrality, i.e. zero net greenhouse gas emissions, the transformation of the economy towards sustainable development, a sustainable food system and the protection of biodiversity. Most important, however, is the decarbonisation of the economy. However, the drive to reduce greenhouse gas emissions is not the novelty in the European Union's economic policy, as this task has been pursued since 2005 when the Kyoto Protocol treaty came into force. What distinguishes these regulations is the fact that the targets are ambitious and commit governments to green goals up to zero emissions. In terms of energy, the Green Deal aims to ensure an affordable and secure energy supply, energy efficiency and the development of renewable energy sources (RES). It is impossible to see how this indirectly affects both industry (Gajdzik et al., 2024a) and households (García-Vaquero et al., 2024). Industry is mainly affected in the form of necessary investments to reduce greenhouse gas emissions or production productivity (Halkos, Aslanidis, 2024; Nagaj et al., 2024), while households are affected in the form of prices and expenditures on energy carriers (Wysokińska, 2024), which may consequently affect the phenomenon of energy poverty.

To date, the literature has not analysed the impact of the EGD on the economy, energy prices or other spheres of social life very extensively. There have, of course, been some such analyses, but not many so far. Figure 1 shows the research areas that the literature addresses in the analysis of the EGD and the relationship between the EGD and energy prices.

The most extensively analysed so far has been the impact on energy policy, what types of energy feedstocks are used in industry, changes in the supply of fossil fuels, environmental changes and how demand has responded to the assumptions made in EGD. There have also been analyses of how the Green Deal has affected the functioning of energy markets (Nagel et al., 2023), energy prices (Wysokińska, 2024), or the challenges facing energy markets in the face of the war in Ukraine (Arrayo, 2023). Analysing the literature to date, it is noticeable that changes in industry, energy policy and the area of energy prices are highlighted. All this raises the question of whether the EGD arrangements will also affect consumers, their ability to purchase energy carriers and, more broadly, their accessibility to energy carriers. The aim of this manuscript is to investigate whether the regulations adopted under the European Green Deal have an impact on energy poverty in Poland. This objective is guided by three research tasks (RTs):

RT1: to estimate the energy poverty rate in Poland.

RT2: to review the literature concerning potential effects of European Green Deal and factors that may determine energy poverty.

RT3: to analyse the impact of EGD package on the level of energy poverty in Poland.

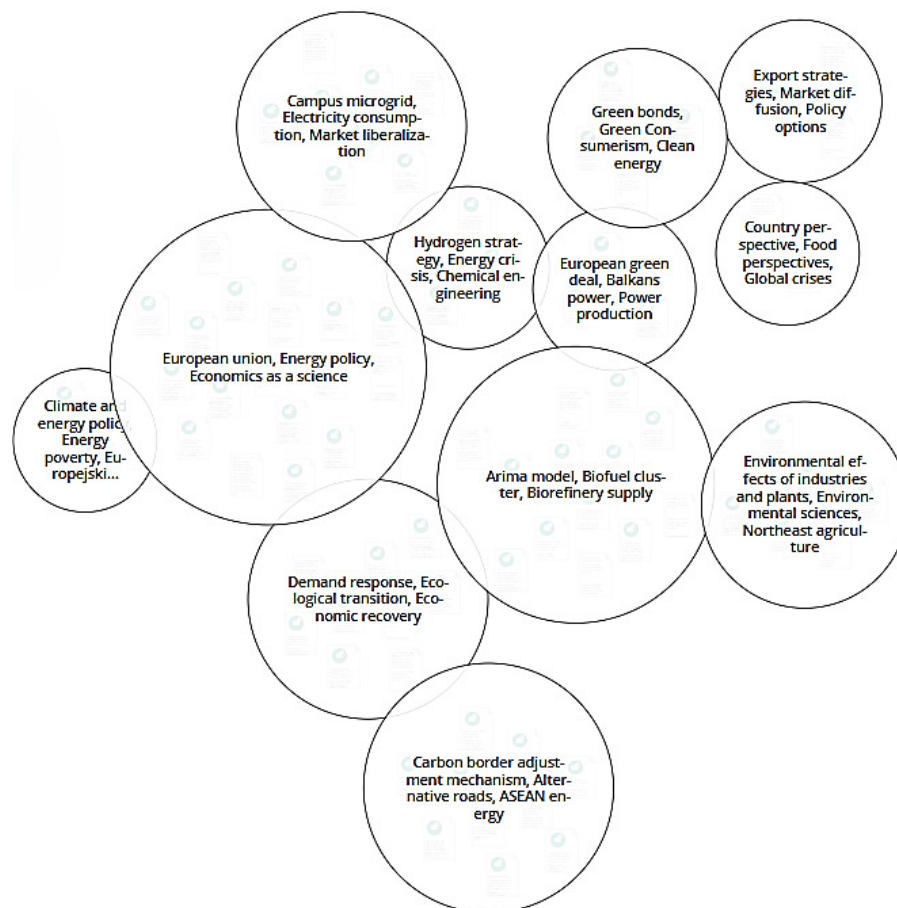


Figure 1. Topics of works in the literature analysing the role of the European Green Deal and the relationship with energy poverty and energy prices.

Source: Open Knowledge Maps (2024). Knowledge Map of green deal and energy prices. Retrieved from: <https://openknowledgemaps.org/map/15b6398b6d0803bf8d8c4fe0083bfde8>, 10.11.2024.

The research tasks formulated in this way are accompanied by the following research questions (RQs):

RQ1: What are determinants of the energy poverty rate in Poland?

RQ2: What is the effect of European Green Deal package on energy poverty in Poland?

RQ3: What is the impact of CO₂ emissions on the level of energy poverty in Poland?

So far, the links between EGD and fuel poverty have not been analysed in the literature. When analysing the literature in detail, the connection between the two phenomena was only found in one paper by García-Vaquero et al. (2024). In this paper, the authors pointed out that the green transition in Austria influences a decrease in GDP and, thus, an increase in poverty. More studies on this topic are unavailable, making this study a novelty to the literature.

In addition to filling a research gap, this work's formulated aim seems relevant for several reasons. First, the effects of EGD on energy poverty have not yet been analysed. Second, if such a potential impact exists, it also justifies the need for deep decarbonisation changes in industry, which is one of the main emitters of greenhouse gases, including CO₂, in the Polish economy. Third, the existence of such links would highlight the need to redefine the concept of energy poverty.

The analysis covers the period 2005-2023. As the Green Deal is linked to decarbonisation policy, to capture the impact of the resulting commitments, the base period covers a period before comparable data is available.

The work structure is as follows: the first section presents the background of the analysis based on a narrative literature review about energy poverty and its determinants; the second section concerns the materials and methods used during the empirical analysis; the next section presents the research results of the analysis and discusses them; and the last section is a set of conclusions.

2. Background for analysis

The issue of energy poverty is defined differently in the literature and, most significantly, addressed to different target groups (Mathen, Sadath, 2022; Zainudin et al., 2023). Most commonly, it is defined in the literature as the inability to consume energy due to a lack of affordable energy carriers (Li et al., 2014; Nagaj, 2022) or due to insufficient income or socio-environmental factors (Makridou et al., 2024), regional (Andreoni, 2024) or related to a lack of physical access (Acharya, Sadath, 2019; Mathen, Sadath, 2022). In the first case, instead of the term energy poverty, the literature uses the term fuel poverty (Bouzarovski, Petrova, 2015), indicating that poor energy is "in fact" a fuel-poor household that is unable to meet its energy needs due to the high price of energy carriers. Since this type of poverty is associated with a lack of access to affordable energy resources, it most often affects developed countries. In the second understanding of energy poverty, this phenomenon most often involves societies or people living in regions where, due to low-income levels or membership in a particular social group or for environmental reasons, they cannot afford to purchase sufficient amounts of energy resources. Region, gender and culture are also considered responsible for energy poverty here (Betto et al., 2020). A third understanding of energy poverty is related to a lack of physical access to energy services. Most often, being energy-poor means difficulties for children with studying and doing their homework, using computers due to lack of electricity, difficulties finding jobs, or securing sufficient life services such as medical services (Acharya, Sadath, 2019; Lenz et al., 2017). However, regardless of how fuel poverty is understood, the literature distinguishes several factors that determine the extent of fuel poverty. Table 1 presents a literature review on the factors of fuel poverty. This review includes publications covering post-European Green Deal analyses.

Table 1.*Factors of energy poverty*

Literature	Factors
Tasinga et al. 2024	Socio-economic factors, scalability of microgrids
Lehtonen et al. (2024)	Socio-economic status, charakterystyka zasobów budowlanych
Chan, Delina (2023)	Socio-economic factors, urbanisation and warmer temperatures, accessibility, affordability, flexibility, energy efficiency, needs, and practices
Lippert, Sareen (2023)	Stan infrastruktury
Hihetah et al. (2024)	Geographic coverage, gender, life stage, ethnicity, peoples abilities
Jayalath et al. (2024)	Local climate conditions, building stock and specific energy consumption patterns of the occupants
Nagel et al. (2023)	ETS allowance prices
García-Vaquero et al. (2024)	Social well-being, GDP

Source: own study.

As Tasinga et al. (2024) point out, renewable energy microgrids contribute to socio-economic development by improving living conditions. This results in higher GDP change, environmental benefits and consequently increased access to energy services. Hihetah et al. (2024) point out that there are many determinants of vulnerability to energy poverty. Therefore, they distinguish here such as geographic coverage, gender, life stage, ethnicity, and people's abilities. They all determine vulnerability to being energy-poor, especially in developing countries. Similarly, socioeconomic status, albeit along with building stock characteristics, is pointed out by Lehtonen et al. (2024). They note that energy poverty affects not only developing countries but also developed economies. Meanwhile, factors related to climate, the local climate conditions, building stock and specific energy consumption patterns of the occupants are highlighted by Jayalath et al. (2024). According to them, these factors determine the level of energy efficiency, which translates into the consumption needs of society. In addition to those mentioned above, Chan and Delina (2023) further distinguish accessibility, affordability, flexibility, energy efficiency, needs, and practices that, according to the authors, influence a household's vulnerability to energy poverty. Lippert and Sareen, on the other hand, point out that the state of the infrastructure, especially the energy infrastructure that would provide the opportunity for transitioning to low-carbon energy, may be necessary at present. Somewhat continuing this kind of analysis are the conclusions presented by Nagel et al. (2023), who, analysing the impact of the Green Deal on the Nordic energy market, pointed out that the effect to date has been increases in the price of CO₂ allowances (ETS) and more significant fluctuations in energy prices. They found that decarbonisation measures to date have resulted in a slight impact on electricity production and a slight impact on the heat market. In contrast, they found increased conversion of electricity to heat. Thus, energy prices are rising, negatively affecting cheap energy availability. Somewhat similar conclusions are drawn by García-Vaquero et al. (2024), who point out that the green energy transition in Europe leads to inflation and structural poverty. They point out that it is possible to speak of a green financial bubble and a paradox according to which, in order to achieve greater future social welfare through the Green Deal, the effect is now a decrease in GDP.

Analysing all the drivers of change in energy poverty levels identified, it was found that in addition to the usual factors of income and level of socio-economic development, attention was also given to factors related to decarbonisation. This is perfectly illustrated by the division introduced by Chan and Delina (2023), who, as part of their analysis, mention the so-called ‘hidden energy poverty’, where, in the context of energy poverty, they divide this phenomenon into the poverty of clean and non-clean fuels. In this context, it is essential to mention the assumptions of the Green Deal and its implications. The Green Deal aims to achieve energy neutrality by 2050 (with an intermediate target of a net reduction of at least 55% by 2030 compared to 1990). The means to do this is to promote renewables, with a RES target of 42.5% in the energy mix. by 2030 and an improvement in energy efficiency by 11.7% by 2030 (European Commission, 2024b). Its implementation involves significant changes in the industrial sector and households.

The main impacts on the industry are:

- a reduction in the carbon footprint of industry (Gajdzik et al., 2024b),
- increased production costs in sectors dependent on fossil fuels, especially in mining industries (Moita et al., 2024; Mali et al., 2024),
- the need to invest in new technologies, especially RES (Gajdzik et al., 2024a),
- an increase in investment in low-carbon technologies that promote the reduction of CO₂ emissions would increase the energy efficiency of production. Mainly, innovations in the area of clean hydrogen and energy storage are expected (Na et al., 2025),
- transformation of business models towards improved energy efficiency and a closed-loop economy (Na et al., 2025).

The main impacts on households are:

- increased energy prices (Wysokińska, 2024),
- increased cost of living and the risk of worsening energy poverty in some regions (García-Vaquero et al., 2024),
- anticipated improvements in the energy efficiency of buildings, resulting from increased funding to support households insulating buildings (Nagel et al., 2023),
- environmental education and awareness, to which the EU is devoting increasing resources. The anticipated result should be increased environmental awareness and changes in consumer behaviour (Liang et al., 2024).

3. Materials and Methods

The literature review indicated that the European Green Deal aims to decarbonise the economy, improve energy efficiency, mainly in the industrial sector, promote greater use of renewable energy sources and ensure sustainability of economic development. As the aim of this paper is to examine what impact the Green Deal, and more specifically its targets, has on energy poverty in Poland, the analysis will follow the model presented in Figure 2.

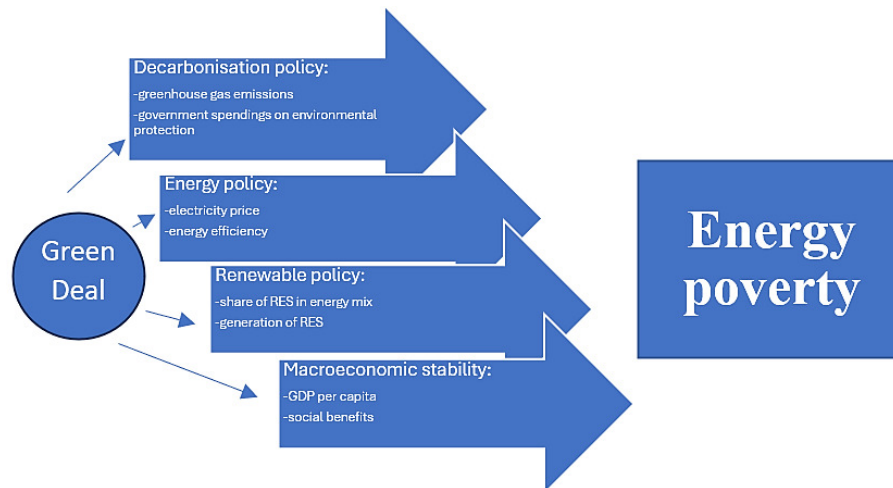


Figure 2. Model for analysing the impact of the Green Deal on energy poverty.

Source: own method of analysis.

Based on the assumptions of EGD, the model assumes 4 areas of influence: decarbonisation policy, energy policy, renewable policy, and macroeconomic stability. In each of these areas of EGD influence, 2 impact indicators were used for the analysis. Their selection is justified by the literature on energy poverty (see Table 1).

In turn, the Energy Poverty Index (EPI), which is a two-dimensional measure, i.e. consisting of 2 indicators, was applied to measure energy poverty:

- inability to keep home adequately warm (IKHAW) (European Energy Network, 2019),
- share of households in the country whose expenditure on energy carriers exceeds 10% of their disposable income (HEECDI) (Boardman, 1991; Nagaj, 2022).

This takes the approach that the weights to the indicators for measuring the EPI index will be equal. This approach can be employed if the importance of the dimensions does not differ significantly (Atkinson et al., 2003), and is additionally consistent with the literature on multicriteria energy poverty indices (Koomson, Danquah, 2021). In accordance with the methodology for creating such indices, the variables are weighted equally when constructing the availability or access to energy carriers index. Thus, the shares will be 0.5 and 0.5, and the EPI will be calculated according to the formula:

$$EPI = \sum_i^t (w_i \cdot IKHAW_t + w_i \cdot HEECDI_t), \quad (1)$$

where:

w_i – the weight value of a given indicator, where $i = 1, 2$;

t – period, i.e. the year for which the indicator is calculated;

$IKHAW_t$ – value of the indicator of inability to keep home adequately warm in a given period t ;

$HEECDI_t$ – share of expenditures on energy carriers in disposable income of households in given period t .

Therefore, the econometric model by which the regression analysis will be carried out is as follows:

$$Y = a + b_1 \cdot X_1 + b_2 \cdot X_2 + b_3 \cdot X_3 + b_4 \cdot X_4 + b_5 \cdot X_5 + b_6 \cdot X_6 + b_7 \cdot X_7 + b_8 \cdot X_8, \quad (2)$$

where:

Y – energy poverty index in Poland (dependent variable);

a – constant parameter, ie. Y intercept;

$b_{1,...,8}$ – coefficients of the regression function for independent variables ($i = 1, \dots, 8$);

$X_1, X_2, \dots, X_n$ – independent variables affecting the dependent ($n = 1, \dots, 10$).

According to the model (see Figure 2), the following indicators were used to measure the independent variables used in the econometric model:

X_1 – CO2 emissions per capita (Jones et al., 2024 – with major processing by Our World in Data);

X_2 – general government expenditure on environmental protection (mln euro) (Eurostat, 2024b);

X_3 – electricity prices for household consumers - band DB (in national currency) (Eurostat, 2024a);

X_4 – energy efficiency measured by the primary energy consumption per GDP (kWh per international-\$) (U.S. Energy Information Administration, 2023; Energy Institute – Statistical Review of World Energy, 2024; Bolt, van Zanden - Maddison Project Database, 2023 – with major processing by Our World in Data);

X_5 – share of primary energy consumption that comes from renewables (Energy Institute - Statistical Review of World Energy, 2024 – with major processing by Our World in Data);

X_6 – Production of modern renewable electricity (from wind, hydro, solar, other renewables including bioenergy in TWh) (Ember, 2024; Energy Institute – Statistical Review of World Energy, 2024 – with major processing by Our World In Data);

X_7 – GDP per capita in current prices in USD (World Bank, 2023 – with minor processing by Our World In Data),

X_8 – Share of social benefits to households in GDP (OECD, 2024).

Calculations are performed using Statistica 13.1 software, at $\alpha = 0.05$. The research period is 1995-2023. The research period results from the fact that data have been available since 1995.

4. Results

When proceeding with the analysis, the EPI value was first calculated. The results of these calculations are shown in Figure 3.

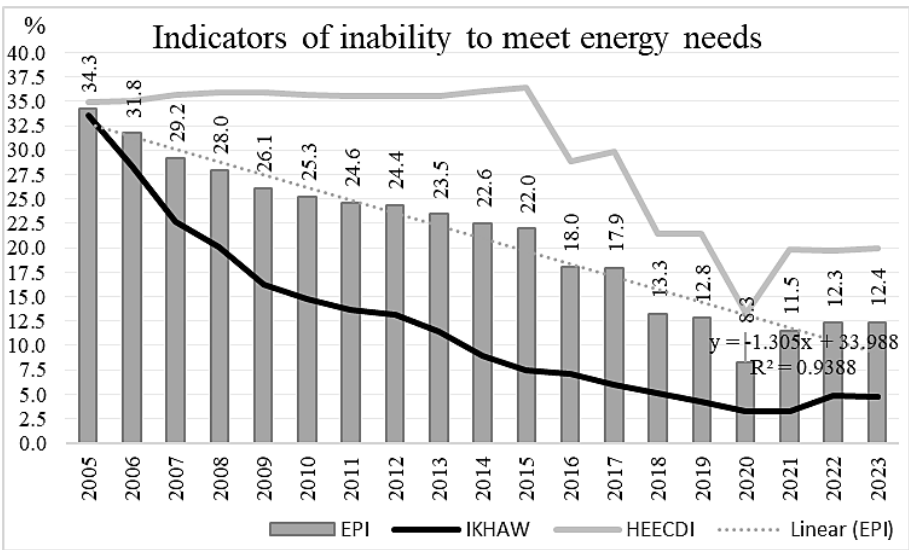


Figure 3. Indicators of inability to meet energy needs and energy poverty index in 2005-2023 in Poland.

Source: European Commission, Energy Poverty Advisory Hub. *National indicators*. Retrieved from: <https://energy-poverty.ec.europa.eu/epah-indicators> (13.11.2024); own calculations based on: Budżety gospodarstw domowych [Household budgets], GUS, Warsaw. Publications for years 2006-2023.

Analysis of the development of the EPI indicated that there was a decreasing trend of energy poverty in Poland over the research period. This concerned both inability to keep home adequately warm and too high a percentage of income spent on energy carriers. It is worth noting, however, that with regard to keeping home adequately warm, the percentage of the energy-poor society was low at only 4.7%, while with regard to spending on all energy carriers, this percentage of households in Poland was much higher at 20% in 2023. However, when analysing the development of the energy poverty index value in the context of the European Green Deal, it is worth noting that the scale of this poverty increases from 2021 onwards. Crucially, such a relationship is observed for both components of the EPI.

The development of EPI levels indicated that there was undoubtedly an increase in the proportion of energy-poor households after 2020, the adoption of the EGD regulations. This raises the assumption that the EGD provisions and the intensification of related activities were the driving factor. However, in order to find out which dimensions had a decisive influence, a regression analysis will be used. The analysis was carried out for annual data from 2005 to 2023. The results of the regression analysis are shown in Table 2.

Table 2.*Results of regression analysis for the energy poverty index in Poland*

	Coefficients b^*_i	Standard error of b^*_i	Coefficients b_i	Standard error of b_i	t-statistic	p-value
N = 19	Regression statistics: R = 0.9930; R ² = 0.9860; Adjusted R ² = 0.9816; F = 228.26; p < 0.0000; Standard error: 1.0161					
Constant			42.4193	8.6810	4.8864	0.0003
Variable X4	-0.8747	0.1328	27.0736	4.1094	6.5881	0.0000
Variable X6	0.8152	0.1640	0.6222	0.1252	4.9704	0.0003
Variable X7	-0.8180	0.1458	-0.0011	0.0002	-5.6102	0.0001
Variable X8	-0.2332	0.0396	-2.4362	0.4132	-5.8958	0.0001

Source: own work.

The results of regression analysis indicated that a statistically significant impact on energy poverty is caused by 4 variables (X4, X6, X7, X8), i.e. energy efficiency, level of production of renewable energy sources, GDP per capita and level of social benefits in Poland. The remaining variables, despite correlations at an average level, do not have a statistically significant impact on the level of EPI. It is also worth noting that, throughout the research period, the greatest influence was exerted by the level of energy intensity - X4 (the value of the relationship with energy intensity is negative, indicating a positive relationship with energy efficiency). However, when considering the aggregate impact of each of the dimensions affected by the EGD, the dimension of household macroeconomic stability, represented in the model by GDP per capita and the level of social benefits, proved to be the most significant.

It is also worth comparing the level of correlation of the independent variables with the dependent variable for the entire research period (2005-2023) and the period under EGD regulation (2020-2023). This comparison will indicate which variables in the last 4 years have had the highest correlation with the development of the level of energy poverty and thus the changes that have occurred in the level of EPI.

Table 3.*Correlation coefficients of independent variables having a statistically significant impact on the EPI calculated for the years 2005-2023 and 2020-2023*

	2005-2023	2020-2023
Variable X4	0.9465	-0.5960
Variable X6	-0.8874	0.7422
Variable X7	-0.9602	0.9298
Variable X8	-0.52735	-0.9079

Source: own work.

A comparison of the levels of the correlation index for the whole period under study (2005-2023) with the correlation values for 2020-2023 shows that there was a change in the direction of the relationship with the EPI for energy efficiency, RES production and GDP per capita. This may explain why there was a change of direction in the EPI level after 2020. However, it is also worth noting that the macroeconomic dimension, for which the correlation coefficients remained high, proved to be very important.

6. Discussion and Conclusions

The aim of the article was to investigate whether the regulations undertaken as part of the European Green Deal have an impact on energy poverty in Poland. This objective was due to the fact that the literature so far has not analysed the relationships between the Green Deal and energy poverty. The literature review indicated that there are few analyses of the impact of the EGD on socio-economic development and none for Poland in relation to energy poverty. As EGD implies decarbonisation of the economy, improvement of energy efficiency, promotion of renewable energy sources while ensuring sustainable economic development, hence the author of this manuscript focused on the analysis of what are determinants of the energy poverty rate in Poland (RQ1), the effect of EGD on energy poverty in Poland (RQ2) and the assessment of whether changes in the level of CO₂ emissions affect the level of energy poverty in Poland (RQ3).

The study concludes that the long-term energy poverty rate in Poland shows a decreasing trend, and this applies both to the inability to keep home adequately warm and to the too high percentage of income spent on energy carriers. However, the analysis indicated that after 2020 there was a change in the trend from declining to increasing, coinciding with the enactment of the EGD regulations. In verifying the answer to RQ1, it was found that of the dimensions of the impact of EDG regulations, three of them have a statistically significant impact on energy poverty, i.e. energy policy and within it the development of energy efficiency, RES promotion policy and especially the level of production of renewable energy sources, and the macroeconomic stability of households, i.e. the level of GDP per capita and social benefits in Poland. These findings are consistent with those presented by Tasinga et al. (2024), Lehtonen et al. (2024) and García-Vaquero et al. (2024) on the leading role of socio-economic factors. Findings in this paper are in contrast to findings presented by Nagel et al. (2023), which is linked to the fact that electricity prices have been subsidised by the government in Poland in recent years. Responding to RQ3, it was found that decarbonising the economy by reducing CO₂ emissions has no direct impact on the level of energy poverty in Poland, which is in contrast to the findings articulated by Jayalath et al. (2024).

Responding to RQ2, the analysis carried out in this manuscript indicated that EGD influenced the increase in the value of EPI, and the macroeconomic dimension of EGD appeared to be the most relevant here. This can be explained by the findings indicated by García-Vaquero et al. (2024), according to which the green energy transition in Europe leads to inflation, structural poverty and negatively affects GDP, with a consequent impact on the macroeconomic well-being of society. Hence, the role of GDP per capita and social benefits in shaping the level of energy poverty in Poland in the period from 2020 proved to be most crucial here.

The findings provided in this paper appear to be a valuable added value to the study of energy poverty and contribute to the literature by analysing the role of EGD in shaping this phenomenon. It is also a valuable recommendation for decision-makers and industry representatives that energy efficiency, which reduces the demand for energy consumption, is not only an important action for companies in the form of costs reductions, but also has a social dimension by contributing to a reduction in the level of energy poverty among households. The author is also aware of the research limitations of this work. The main one is that the research period for the analysis of the impact of the EDG is too short. This is due to the objective limitations that the EGD regulations are only in force from 2020. This makes long-term analyses impossible. Undoubtedly, such cause-and-effect analyses would enrich this analysis. However, this is a recommendation for future research in this scientific area.

References

1. Acharya, R.H., Sadath, A.C. (2019). Energy poverty and economic development: Household-level evidence from India. *Energy and Buildings*, Vol. 183, pp. 785-791. <https://doi.org/10.1016/j.enbuild.2018.11.047>.
2. Andreoni, V. (2024). Energy poverty in EU: Using regional climatic conditions and incidence of electricity prices to map vulnerability areas across 214 NUTS2 European regions. *World Development Sustainability*, Vol. 4, 100146. <https://doi.org/10.1016/j.wds.2024.100146>.
3. Arroyo, E.N. (2023). The Climate Emergency: Putting Consumers at the Heart of the European Green Deal Following Russia's War on Ukraine. *Global Energy Law and Sustainability*, Vol. 4, No. 1-2, pp. 51-71. <https://doi.org/10.3366/gels.2023.0093>
4. Atkinson, A.B. (2003). Multidimensional deprivation: contrasting social welfare and counting approaches. *Journal of Economic Inequality*, Vol. 1, pp. 51-65.
5. Betto, F., Garengo, P., Lorenzoni, A. (2020). A new measure of Italian hidden energy poverty. *Energy Policy*, Vol. 138, 111237. <https://doi.org/10.1016/j.enpol.2019.111237>.
6. Boardman, B. (1991). *Fuel Poverty: From Cold Homes to Affordable Warmth*. London, UK: Belhaven Press.
7. Bouzarovski, S., Petrova, S. (2015). A global perspective on domestic energy deprivation: Overcoming the energy poverty–fuel poverty binary. *Energy Research & Social Science*, Vol. 10, pp. 31-40. <https://doi.org/10.1016/j.erss.2015.06.007>.
8. Chan, C., Delina, L.L. (2023). Energy poverty and beyond: The state, contexts, and trajectories of energy poverty studies in Asia. *Energy Research & Social Science*, Vol. 102, 103168. <https://doi.org/10.1016/j.erss.2023.103168>.

9. Ember (2024). Energy Institute – Statistical Review of World Energy (2024). – with major processing mby Our World In Data. *Modern renewable energy generation by source*. Retrieved from: <https://ourworldindata.org/grapher/modern-renewable-prod>, 13.11.2024.
10. Energy Institute – Statistical Review of World Energy (2024) – with major processing by Our World in Data. *Share of primary energy consumption that comes from renewables*. Retrieved from: <https://ourworldindata.org/grapher/renewable-share-energy>, 13.11.2024.
11. European Commission (2024a). *European Green Deal. Striving to be the first climate-neutral continent*. Retrieved from: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en, 10.11.2024.
12. European Commission (2024b). *2050 long-term strategy. Striving to become the world's first climate-neutral continent by 2050*. Retrieved from: https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en, 11.11.2024.
13. European Energy Network (2019). *EnR Position Paper on Energy Poverty in the European Union*. Italian Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Energy Efficiency Department: Roma, Italy. Retrieved from: <https://enr-network.org/wp-content/uploads/ENERGYPOVERTY-EnRPositionPaper-Energypoverty-Jan-2019.pdf>, 15.11.2024.
14. Eurostat (2024a). *Electricity prices for household consumers - bi-annual data*. Retrieved from: https://ec.europa.eu/eurostat/databrowser/view/nrg_pc_204/default/table?lang=en&category=nrg.nrg_price.nrg_pc, 12.11.2024.
15. Eurostat (2024b). *General government expenditure by function (COFOG)*. Retrieved from: https://ec.europa.eu/eurostat/databrowser/view/gov_10a_exp__custom_11105433/default/table?lang=en, 28.04.2024.
16. Gajdzik, B., Nagaj, R., Wolniak, R., Bałaga, D., Žuromskaitė, B., Grebski, W.W. (2024a). Renewable Energy Share in European Industry: Analysis and Extrapolation of Trends in EU Countries. *Energies*, Vol. 17, No. 11, 2476. <https://doi.org/10.3390/en17112476>.
17. Gajdzik, B., Wolniak, R., Nagaj, R., Žuromskaitė-Nagaj, B., Grebski, W.W. (2024b). The Influence of the Global Energy Crisis on Energy Efficiency: A Comprehensive Analysis. *Energies*, Vol. 17, No. 4, 947. <https://doi.org/10.3390/en17040947>
18. García-Vaquero, M., Daumann, F., Sánchez-Bayón, A. (2024). European Green Deal, Energy Transition and Greenflation Paradox under Austrian Economics Analysis. *Energies*, Vol. 17, No. 15, 3783. <https://doi.org/10.3390/en17153783>.
19. Halkos, G.E., Aslanidis, P.-S.C. (2024). Green Energy Pathways Towards Carbon Neutrality. *Environmental and Resource Economics*, 87, pp. 1473-1496. <https://doi.org/10.1007/s10640-024-00856-z>
20. Hihetah, C., Gallachóir, B., Dunphy, N.P., Harris, C. (2024). A systematic review of the lived experiences of the energy vulnerable: Where are the research gaps? *Energy Research & Social Science*, Vol. 114, 103565. <https://doi.org/10.1016/j.erss.2024.103565>.

21. Jayalath, A., Vaz-Serra, P., Hui, F.K.P., Aye, L. (2024). Thermally comfortable energy efficient affordable houses: A review. *Building and Environment*, Vol. 256, 111495. <https://doi.org/10.1016/j.buildenv.2024.111495>.
22. Jones et al. (2024). *Population based on various sources (2023) – with major processing by Our World in Data*. Retrieved from: <https://ourworldindata.org/grapher/per-capita-ghg-emissions>, 16.11.2024.
23. Koomson, I., Danquah, M. (2021). Financial inclusion and energy poverty: Empirical evidence from Ghana. *Energy Economics*, Vol. 94, 105085.
24. Lehtonen, O., Hiltunen, A.P., Okkonen, L., Blomqvist, K. (2024). Emerging spatial clusters of energy poverty vulnerability in rural Finland—Byproducts of accumulated regional development. *Energy Research & Social Science*, Vol. 109, 103418. <https://doi.org/10.1016/j.erss.2024.103418>.
25. Lenz, L., Munyehirwe, A., Peters, J., Sievert, M. (2017). Does Large-Scale Infrastructure Investment Alleviate Poverty? Impacts of Rwanda's Electricity Access Roll-Out Program. *World Development*, Vol. 89, pp. 88-110. <https://doi.org/10.1016/j.worlddev.2016.08.003>.
26. Li, K., Lloyd, B., Liang, X.-J., Wei, Y.-M. (2014). Energy poor or fuel poor: What are the differences? *Energy Policy*, Vol. 68, pp. 476-481. <https://doi.org/10.1016/j.enpol.2013.11.012>.
27. Liang, H., Wu, Z., Du, S. (2024). Study on the impact of environmental awareness, health consciousness, and individual basic conditions on the consumption intention of green furniture. *Sustainable Futures*, Vol. 8, 100245. <https://doi.org/10.1016/j.sftr.2024.100245>.
28. Lippert, I., Sareen, S. (2023). Alleviation of energy poverty through transitions to low-carbon energy infrastructure. *Energy Research & Social Science*, Vol. 100, 103087. <https://doi.org/10.1016/j.erss.2023.103087>.
29. Makridou, G., Matsumoto, K., Doumpos, M. (2024). Evaluating the energy poverty in the EU countries, *Energy Economics*, Vol. 140, 108020. <https://doi.org/10.1016/j.eneco.2024.108020>.
30. Malik, A., Lafortune, G., Mora, C.J., Carter, S., Lenzen, M. (2024). Carbon and social impacts in the EU's consumption of fossil and mineral raw materials. *Journal of Environmental Management*, Vol. 369, 122291. <https://doi.org/10.1016/j.jenvman.2024.122291>.
31. Mathen, C.K., Sadath, A.C. (2022). Examination of energy poverty among households in Kasargod District of Kerala. *Energy for Sustainable Development*, Vol. 68, pp. 472-479. <https://doi.org/10.1016/j.esd.2022.04.018>.
32. Moita, A., Lopes, J.C., Mendes, J.Z. (2024). Circular economy and sustainability: The case of the automotive industry in Portugal. *Innovation and Green Development*, Vol. 3, No. 4, 100177. <https://doi.org/10.1016/j.igd.2024.100177>.
33. Na, H., Yuan, Y., Sun, J., Zhang, L., Du, T. (2025). Integrative optimization for energy efficiency, CO2 reduction, and economic gains in the iron and steel industry: A holistic

- approach. *Resources, Conservation and Recycling*, Vol. 212, 107992. <https://doi.org/10.1016/j.resconrec.2024.107992>.
34. Nagaj, R. (2022). Macroeconomic Policy Versus Fuel Poverty in Poland—Support or Barrier. *Energies*, Vol. 15, No. 13, 4710. <https://doi.org/10.3390/en15134710>.
35. Nagaj, R., Gajdzik, B., Wolniak, R., Grebski, W.W. (2024). The Impact of Deep Decarbonization Policy on the Level of Greenhouse Gas Emissions in the European Union. *Energies*, Vol. 17, No. 5, 1245. <https://doi.org/10.3390/en17051245>.
36. Nagel, N.O., Böhringer, Ch., Rosendahl, K.E., Bolkesjø, T.F. (2023). Impacts of green deal policies on the Nordic power market. *Utilities Policy*, Vol. 80, 101475. <https://doi.org/10.1016/j.jup.2022.101475>.
37. OECD (2024). *Social benefits to households (indicator)*. Retrieved from: <https://doi.org/10.1787/423105c6-en>, 16.11.2024.
38. Tamasiga, P., Onyeaka, H., Altaglibi, M., Bakwena, M., Ouassou, E. (2024). Empowering communities beyond wires: Renewable energy microgrids and the impacts on energy poverty and socio-economic outcomes. *Energy Reports*, Vol. 12, pp. 4475-4488. <https://doi.org/10.1016/j.egyr.2024.10.026>.
39. U.S. Energy Information Administration (2023); Energy Institute - Statistical Review of World Energy (2024); Bolt and van Zanden - Maddison Project Database 2023 - with major processing by Our World in Data. *Primary energy consumption per GDP*. Retrieved from: <https://ourworldindata.org/grapher/energy-intensity?tab=table>, 13.11.2024.
40. World Bank (2023) – with minor processing by Our World In Data. *GDP per capita*. Retrieved from: <https://ourworldindata.org/grapher/gdp-per-capita-worldbank>, 13.11.2024.
41. Wysokińska, Z. (2024). Energy Policy in the European Union within the European Green Deal Strategy. *Comparative Economic Research*, Vol. 27, No. 2, pp. 73-91.
42. Zainudin, N., Mohamad, U.K., Osman, S., Lau, J.L., Jusoh, Z.M., Nordin, N. (2023). What is energy poverty? A concept analysis. *International Journal of Academic Research in Business and Social Sciences*, Vol. 13, No. 18, pp. 366-379. <http://dx.doi.org/10.6007/IJARBS/v13-i18/19971>.

ANALYSIS OF HUMAN CAPITAL EFFICIENCY IN POLISH ENERGY COMPANIES

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Purpose: The Polish energy sector faces the need to change the production structure generates high demands, among others, on the sector's staff. Therefore the aim of the article is to analyse the efficiency of human capital in energy sector enterprises in Poland in the period 2010-2023.

Design/methodology/approach: The model chosen to estimate the efficiency and value of human capital is Pulic' VAICTM, which was compared with employee performance indicators. The study was conducted for six energy companies.

Findings: The research results indicate an increase in the efficiency and value of human capital, although they vary in individual companies. The basic factors determining the diversity of the results obtained are changes in the level of employment, different shares of coal in energy production and different shareholding structures. VAICTM has proven to be stable method for estimating human capital efficiency in both the long and short term.

Research limitations/implications: The study was conducted with reference to energy entities operating in the Polish economic and energy specifics. In the perspective of further research, it is appropriate to expand the study entities to companies operating in other markets.

Practical implications: The VAICTM approach and employee productivity indicators indicate a different hierarchy of companies in terms of human capital efficiency, therefore they should be used together, as complementary, and interpreted appropriately.

Originality/value: The contribution of the article to the existing literature is the repetition of research aimed at verifying the use-fulness of the VAICTM model in estimating the efficiency of human capital and the confrontation of this indicator with employee performance indicators.

Keywords: value of human capital, human capital efficiency, energy companies, VAICTM, work efficiency.

Category of the paper: Research paper.

1. Introduction

Enterprises are increasingly looking for competitive advantage in intangible resources (Lerro et al., 2014), such as the value of intellectual capital (Iazzolino et al., 2019), including the potential of human resources (Buzavaite, Korsakiene, 2019; Nilsson, Ford, 2004). Intellectual capital does not have a unique definition, what is more, the authors see its structure differently (Milost, 2005), but human capital is always its integral component which is not divided into smaller elements.

The aim of the article is to assess the growth rate of efficiency and the value of human capital in energy companies in Poland over the last dozen or so years. The authors assume that the increase in the value of human capital is the basis for the increase in the competitiveness of enterprises and the ability to adapt to changing conditions. Human capital is very important in the energy sector in Poland due to the need for deep restructuring and the related challenges for staff.

The VAICTM index proposed by Pulic (1998) was adopted as the basic method for estimating the efficiency and value of human capital. Due to the fact that the literature draws attention to the uncertainty regarding short-term estimates in the case of the VAICTM indicator, this article compares it with changes in alternative work efficiency indicators (sales revenues to personnel costs and sales revenues per employee).

The research problems addressed in the article concern the growth rate of efficiency and the value of human capital in Polish energy companies and the assessment of how well the indicators selected as a research tool reflects these changes in the long- and short-term perspective. In conditions of economic shocks and high inflation (which occurred in the last years of the analysis), changes in the value of human capital based on the level of personnel costs may indicate the strength of trade unions (the pace and amount of negotiated wage increases due to inflation) rather than actual changes in the value of human capital. Therefore, in order to limit the impact of inflation, a deflator was used in the case of the sales revenues per employee indicator.

In the world literature, research using the VAICTM model focuses mainly on the banking and financial sectors (Ozkan et al., 2017). Our contribution to the literature is a supplement and additional verification of the usefulness of the VAICTM indicator in estimating the value of human capital in the energy sector. The undertaken re-search also allows to verify the statement that in the short term, especially in conditions of economic shocks, typical work efficiency indicators based on sales revenues reflect the efficiency of human capital better than VAICTM.

The article consists of a literature review, methodological part, research results, discussions and conclusions. The literature review is divided into three subchapters, presenting the concept and factors influencing human capital, VAICTM as a method of measuring the value of human

capital as well as its efficiency and the challenges facing the Polish energy sector. In the last subchapter of literature review, four research hypotheses were also formulated. In the methodological part, apart from indicating the companies subject to analysis, the assumptions of data analysis were presented, aimed at verifying the hypotheses put forward.

2. Literature review and hypothesis development

2.1. Human capital in theoretical terms

It is most often assumed that the two basic elements of intellectual capital are human and structural capital (Edvinsson, Sullivan, 1996; Edvinsson, Malone 1997; Roos, 1997; Stewart, 1997). Some authors distinguish customer capital (Marr; Moustaghfir, 2005; Martínez-Torres, 2006; Pap et al., 2021) or customer capital and innovative capital (Chen et al., 2004) from structural capital. It should be noted that in all the above approaches, human capital appears as a separate element of intellectual capital and is not divided into smaller components.

Human capital, treated as resources related to the knowledge and skills of an individual, is considered a key element of economic development (Laroche et al., 1999; Lim et al., 2018; Angrist et al., 2021; Dańska-Borsiak, 2023; Zhang et al., 2023). The system that builds initial human capital is the formal education system, treated as a long-term investment in citizens – building their human capital before entering the labour market (Kraay, 2018; Lenkei, 2019; Wosiek, 2020). Appropriate education prepares for technological challenges (Becker, 1993), facilitates innovative activities (Nelson, Phelps, 1966; Mulliqi et al., 2018; Castelló-Climent, 2019; Diebolt, Hippe, 2019; Rossi, 2020), contributes to increasing technical progress, increasing work efficiency (Alataş, Çakir, 2016) and productivity of physical capital (Bodman, Le, 2013; Almendarez, 2013; Queirós, Teixeira, 2016; Wang et al., 2023).

From the perspective of the organization, Schultz (1961, p. 140) proposed the definition of human capital as "knowledge, skills and abilities of the people employed in an organization". Since human capital is the property of an employee who can invest his or her abilities, behaviour and energy in the companies of his or her choice, it is important to encourage him or her to join and stay in the organization in a way that generates benefits for both parties (Davenport, 1999; Mayo, 2001).

From an organizational perspective, human capital is more than the simple sum of the human capital of all employees. Due to cooperation, people co-create processes, practices, norms and standards, react and influence the organization's environment, building structural capital. Individual knowledge, skills and attitudes increase, social relationships and organizational systems are built, which creates values for both the organization and the individual (Storberg-Walker, 2004). The company invests in employee development,

taking into account the profitability of this investment (Lepak, Snell, 1999), preferring forms of development that do not generate direct costs (organized coaching, mentoring, learning-by-doing). Employees themselves can also improve their human capital through self-education (OECD, 1998; CIPD, 2017). Bornemann et al. (1999) indicated that companies that actively supported the development of their intellectual capital achieved better results.

The literature highlights differences in human capital in national, regional and sectoral terms. The current level of human capital in individual countries is historically determined. Its level is largely influenced by general economic institutions (Diebolt, Hippe, 2019; Pritchett, 2001; Acemoglu et al., 2014), including: a well-defined system of property rights, openness of the economy, and national security (Hanushek, Woessmann, 2008). The level of available human capital may explain differences in the development of individual regions and economic sectors (Diebolt, Hippe, 2019; Gennaioli et al., 2013). Migrations at the international, regional and sectoral levels, caused by differences in the level of salaries and working conditions offered there, cause a drain or inflow of innovative personnel to particular markets (Wielechowski et al., 2021; OECD, 1998). Gibbons et al. (2005) show that high-wage sectors employ highly skilled workers and obtain high returns on workers' skills.

Estimating the value of human capital is most often based on cost and/or income methods. From a cost perspective, the human capital of an individual employee is treated as expenditure on acquiring: resources of knowledge, experience and skills acquired at school, during on-the-job training and other forms of further education (Becker, 1993, Marr et al., 2004; Unger et al., 2011; Østergaard, Marinova, 2018). Estimates of the level of human capital based on the costs incurred by the state (providing a formal level of education), the family (expenditures on education, health care), the enterprises that employed the employee (expenditures on training and development at the workplace), and the employee himself are only an approximation value of human capital. They do not take into account the value of the employee's non-market activities (Jorgenson, Fraumeni, 1989), his or her personality traits and individual skills (Son, 2010; Lee, Lee, 2016).

An alternative to the cost approach are profitable methods of measuring human capital. They focus on the efficiency (productivity) of employees, which, according to economic theory, equals the equilibrium wage rate (Buessermann, 2009). In the income approach, efficiency is identified with the received wage rate, which should optimally reflect the entire human capital of the individual (i.e. experience, training, education, health, etc.) (Škare, Lacmanović, 2015). In the literature, estimates of the value of a single employee's human capital based on individual remuneration have been criticized. First, it is difficult to defend the assumption that wage differentials accurately reflect differences in the efficiency of individual workers (Segu, Natoli, 2012). Secondly, the actual level of salaries is influenced by trade unions, which usually strive to convert the wage structure (Ahlroth et al., 1997). These reservations are less important in the case of estimating the human capital of the entire enterprise, which is based on the average performance of all employees.

The research undertaken in the article concerns the importance of human capital as one of the key resources for the development of an organization (Mahmood et al., 2014, Lim et al., 2018; Habib et al., 2019; Angrist et al., 2021), which is an issue important for both the theory of scientific management and management practice. The competitiveness of human resources can be assessed through the prism of human capital efficiency (Dakhli, De Clercq, 2004; Huggins et al., 2017). The level of achieved human capital efficiency indicates the degree of the employees allocation adequacy to tasks, determining the productivity of individual employee and employees teams (Feng, Graetz, 2020; Alekseeva et al., 2021; Schultheiss et al., 2023; Sheveleva et al., 2023). The basic methodological problem is the selection of appropriate measures of the value of human capital and its efficiency.

2.2. VAIC™ as a method for measuring the value of an enterprise's intellectual and human capital

Income methods include the Added Intellectual Value Coefficient (VAIC™), which was proposed by Pulic (1998) as a method for measuring the value of an enterprise's intellectual capital. He assumed that in a knowledge-based economy, employees are responsible for the market results achieved. They have intellectual potential, which consists of their ability to create value through the effective use of infrastructure (material capital) and relationships with the environment (market) (Pulic, 1998, 2008). Pulic proposed that VAIC™ should be treated as the sum of the equity capital coefficient (calculated as the ratio of value added to equity capital), the human capital coefficient (calculated as the ratio of value added to personnel expenses) and structural capital coefficient (calculated as the ratio of structural capital to value added). The sum of mentioned indicators creates an aggregated indicator that shows the company's overall efficiency in creating value and presents its intellectual capabilities (Pulic, 2008). VAIC™ indicates the efficiency of the used potential both in financial and intellectual terms, and can be used at the level of national economies, sectors, enterprises and their parts (Pulic, 2004). The main advantage of this indicator is the availability of data (added value, physical capital, intellectual potential – treated as personnel expenses) that come from the market (Pulic, 2000b). Since VAIC™ is positively related to a company's profitability and market value (Pulic, 2000a), managers can use it as a management tool (to improve the use of physical capital and intellectual potential (due to an increase in employee productivity) and identify internal inefficiencies (Pulic, 2000b).

Pulic emphasizes that human capital covers all employees. A good indicator of the intellectual potential used in an enterprise is the level of expenditures on personnel, treated as compensation for the time invested and knowledge input used. Labour inputs should not be treated as costs, but related to the creation of value by employees, whose involvement is reflected in the value added created (employees are a key resource for value creation) (Pulic, 2004, 2008). Pulic (2000a, 2004) proposes to calculate the efficiency of human capital as the quotient of the value added created in the company by its human capital, identified with total

salaries and benefits paid by company. Value added is an objective indicator of business success (Pulic, 2004), and the coefficient shows the actual productivity of the company's staff (the value that the company obtains from investing one monetary unit in its staff) (Pulic, 2008).

Supporters of the VAIC™ model assume that all employee-related costs are investments in employee knowledge. The company expects a return on these expenditures in the form of an increase in the added value generated (Iazzolino, Laise, 2013). An additional advantage of the indicator is that it is calculated based on publicly available financial statements, the credibility of which is checked during an audit (Tan et al., 2007; Nazari, Herremans, 2007; Young et al., 2009). VAIC™ focuses on assessing the efficiency of intellectual capital related to the use of its components (Iazzolino et al., 2014).

Critics of the Pulic' model point out that although it measures the efficiency of a company's employee and capital investments, human capital and structural capital, the obtained results cannot be identified with intellectual capital (Ståhle et al., 2011; Bakhsha et al., 2017). They also point out that it is not (as its author claims) a universal tool. Taking labour costs as a reference point, in conditions of strong differences in wage levels in individual countries, does not allow for international comparisons (Ståhle et al., 2011).

Andriessen (2004) pointed out that value added results from three sources: human, structural and financial capital. Determining the contribution of each of these three sources to added value requires examining the synergies between them. Additionally, identifying human capital with salary costs means that human capital increases with their increase (Bakhsha et al., 2017). Investing only in employee knowledge, as recommended by VAIC™, does not guarantee a return on investment, because efficiency also depends on other forms of capital (Marzo, 2022). Some of the expenses improving employee knowledge affect the value added in the long term, while the expenses are incurred by the company immediately (Andriessen, 2004), which is also agreed by Pulic (2004), VAIC™ is therefore not a good indicator of changes in human capital in the short term. Additionally, in Pulic' approach, an employee's individual knowledge (human capital) is contrasted with structural capital, treated as the difference between intellectual and human capital (Marzo, 2022).

Research on intellectual capital (including human capital) using the VAIC™ indicator gives mixed results. In the banking sector, most studies indicate a positive relationship between the efficiency of intellectual capital use and financial results. In the case of banks in the USA, it was even found that the efficiency of human capital has a greater impact on financial results than other components of intellectual capital (Meles et al., 2016). Empirical studies in Bangladesh have shown a positive and significant relationship between intellectual capital and bank performance (Nabi et al., 2020). In the case of the banking sector in Turkey, human capital efficiency has a positive impact on banks' performance, with the efficiency of capital employed having a greater impact on financial performance (Ozkan et al., 2017). An exception is the research on the banking sector in Italy (Puntillo, 2009), which did not show any relationship between the studied variables (except for the relationship between employee

efficiency and bank efficiency). Laing et al. (2010) found that the VAICTM model is a robust tool for assessing the efficient use of intellectual resources in the hospitality sector in Australia.

Tan et al. (2007) for Singapore listed companies found that intellectual capital (IC) is positively related to firm performance, future firm performance, and growth rate, with the contribution of IC to firm performance varying by industry. Based on research in Malaysia, Gan and Saleh (2008) concluded that VAICTM can explain profitability and productivity, but does not explain market valuation. Shiu (2006) analysed technology companies in Taiwan and found a positive correlation between VAICTM, profitability and market valuation and a negative correlation with productivity. Chan (2009), based on research conducted in Hong Kong, concluded that the final relationship between intellectual capital (IC) and the four analysed financial performance measures is only moderate. The study also showed that managers highly value physical capital as a factor in improving market valuation, productivity and profitability. Maditinos et al. (2011) found that the financial results of Greek companies indicate a higher valuation by investors of physical capital assets than intellectual capital. Research by Firer and Williams (2003) conducted in South Africa also indicates that investors focus on capital rather than intellectual assets. Additionally, these studies found no relationship between VAICTM and profitability, productivity, and market value.

Taking into account theoretical considerations and the cited research results, the choice of VAICTM as the human capital valuation method for the purposes of this article was dictated by three arguments. Firstly, applying the method only to human capital removes most of the objections raised against VAICTM regarding the connections between the components of intellectual capital and the synergistic effects occurring between them. Secondly, referring the method to the energy sector in Poland removes reservations as to the possibility of using the indicator for comparisons in different countries and different sectors. Third, VAICTM allows the use of reliable and audited data.

2.3. Challenges for the energy sector in Poland

Coal energy in the European Union countries has been under pressure for many years resulting from the climate goals of the Green Deal, i.e. decarbonisation and achieving climate neutrality by 2050 (European Commission, 2020). The tool forcing the expected changes are additional costs imposed on the production of electricity from non-renewable sources due to carbon dioxide emissions (Pach-Gurgul, Ulbrych, 2019; Capros et al., 2014). The energy sector in Poland faces more serious challenges than in other EU countries (Szczepankiewicz and Mućko, 2016), because its energy mix is still dominated by coal – in 2023 in Poland, 39.9% of electricity came from hard coal and 21.1% from lignite (Swoczyna, 2024). The increase in the price of CO₂ emission allowances in recent years has influenced the financial situation and strategic behaviour of Polish energy companies, forcing them to diversify their activities towards the use of low-emission energy sources (Nawrocki, Jonek-Kowalska, 2023).

The state's energy policy aims to reconcile maintaining the availability of power in the energy system with the gradual phase-out of coal-fired units and supporting investments in low- or zero-emission energy sources (Baran et al., 2022). Energy companies are also interested in this type of investments, seeing them as a condition for survival and an opportunity to improve financial results (van Beurden, Goessling, 2008; Zieliński, Adamska, 2022).

One of the conditions for the success of the transformation of the energy sector in Poland is having sufficiently effective human capital (Kuzior et al., 2022). Based on a literature review and assuming that energy companies have taken appropriate steps towards the development of human capital, the first hypothesis was put forward:

H1: The efficiency of human capital in Polish energy companies is gradually increasing.

When formulating the second hypothesis, the gradual economic growth in recent years and the fact that the energy sector in Poland is competitive in terms of salaries were taken into account (therefore, the energy sector rather acquires highly efficient employees than loses them to other sectors). Since the analysed energy companies have a similar history and face similar challenges, but are at different stages of restructuring activities, the following hypothesis was formulated:

H2: The value of human capital per employee in energy enterprises in Poland is growing at a similar pace.

Assuming that the level of salaries is linked to work efficiency (rational actions of enterprises in terms of personnel expenditure) and in connection with the use of work efficiency as an alternative to the VAICTM indicator, it was assumed hypothesis about their positive relationship:

H3: There is a positive correlation between human capital efficiency using the VAICTM index and work efficiency.

Since VAICTM is the proportion of the added value and the estimated value of human capital, it can also be treated as an assessment of the economic efficiency of this capital, assuming that efficiency is the proportion between the effects and inputs of economic activities (McConnell, 1984). Estimating the efficiency and value of human capital in recent years is exposed to deviations from long-term trends due to economic shocks. The first was the Covid-19 pandemic, the second was the outbreak of war in Ukraine, which resulted in, among others, a drastic increase in the prices of energy raw materials (which first affected the energy industry and its customers) and an increase in the inflation rate. Since the VAICTM indicator is based on the level of salaries and their adjustments are postponed in time due to wage negotiation processes, the following hypothesis was put forward:

H4: In the short term, especially in the event of economic shocks, work efficiency is a better picture of changes in human capital efficiency than VAICTM.

3. Research methodology

Energy capital groups listed on the Warsaw Stock Exchange (ENEA, ENERGA, PGE, POLENERGIA, TAURON PE and ZE PAK) that dominate on the supply side of the energy market were selected for the study. In 2023, the three largest producers (PGE, ENEA and TAURON) had a total of over half of the installed capacity and were responsible for over 2/3 of electricity production in Poland (Urząd Regulacji Energetyki, 2024).

The verification of the first three hypotheses regarding the increase in the value of human capital was based on the VAICTM coefficient and staff performance indicators and their growth rates, using data from financial statements published by companies:

$$\text{Efficiency of Human Capital (VAIC)} = \frac{\text{Value Added}}{\text{Salaries and Benefits}} \quad (1)$$

$$\text{Value Added} = \text{Sales Revenues} - \text{Costs of Materials and Energy Consumption} - \text{Costs of External Services} - \text{Value of Sold Goods and Materials} - \text{Taxes and Fees} \quad (2)$$

$$\text{Work Efficiency Based on Number of Employees} = \frac{\text{Sales Revenues}}{\text{Average Number of Employees}} \quad (3)$$

$$\text{Work Efficiency Based on Personnel Costs} = \frac{\text{Sales Revenues}}{\text{Salaries and Benefits}} \quad (4)$$

Since the construction of the indicators is based on financial data expressed in current prices, both in terms of the numerators and denominators, nominal data published by companies were used. In the case of value added calculations (2), due to the different approaches to including CO₂-related costs in energy companies' operating costs (some entities report these costs under taxes and fees, others report them under the costs of materials and energy consumption, and still others do not disclose where they have allocated them), it was decided to include in external operating costs also the "taxes and fees" category.

Due to the intensification of inflation processes in recent years and changes in price regulations imposed by the state regulator, a deflator based on the proportion of changes in nominal and real GDP in the analysed period was used to verify the 4-th hypothesis. This made it possible to obtain data in real prices, which is especially important in the case of the work efficiency based on the number of employees indicator:

$$\text{Real Sales Revenues} = \frac{\text{Nominal Sales Revenues}}{(1+\text{deflator})} \quad (5)$$

$$\text{Real Work Efficiency Based on Number of Employees} = \frac{\text{Real Sales Revenues}}{\text{Average Number of Employees}} \quad (6)$$

As the study considers three different indicators to assess the efficiency of human capital, based on the same sources of financial data, but using different data, a correlation analysis was also assumed between human capital estimated using the VAICTM index and work efficiency indicators. Such calculations will allow to determine whether the results obtained with the indicators used were similar.

4. Research results

Figure 1 shows changes in the efficiency of human capital estimated according to VAICTM in comparison with work efficiency in two approaches (based on number of employees and based on personnel costs). In the case of POLENERGIA, the fastest increase in sales revenues compared to the beginning of the analysed period forced the use of a separate scale (it is the smallest company, which only in 2022 and 2023 exceeded the employment level of 300 people). With a relatively stable increase in efficiency according to VAICTM, what is noteworthy is the dramatic increase in revenue-based efficiency indicators in the last two years (except for POLENERGIA). While this could be expected in the case of the work efficiency based on number of employees indicator (the index's numerator increased due to the increase in energy prices), the slightly lower increase in the work efficiency based on personnel costs indicator indicates a much weaker increase in employee expenditure (than the increase in energy prices).

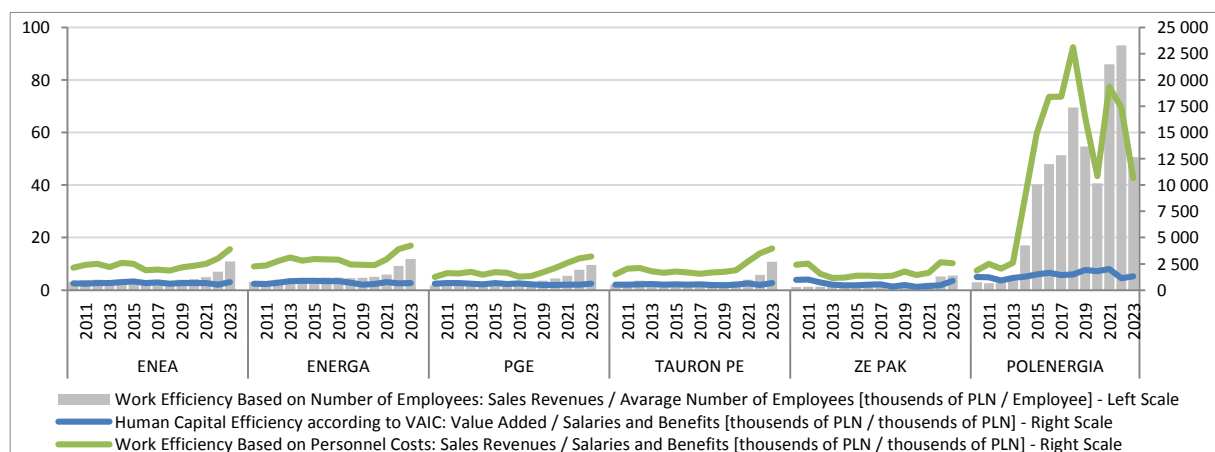


Figure 1. Human capital efficiency and work efficiency in the analysed Polish energy companies in 2010-2023.

Source: Own work.

The percentage changes in the analysed approaches to human capital efficiency are presented in Table 1.

Table 1.

Changes in the efficiency of human capital and work efficiency in the analysed Polish energy companies in 2010-2023

	Human Capital Efficiency According to VAIC TM			Work Efficiency Based on Number of Employees			Work Efficiency Based on Personnel Costs		
	Growth Rate 2010-2023	Annual Growth (Average)	Standard Deviation	Growth Rate 2010-2023	Annual Growth (Average)	Standard Deviation	Growth Rate 2010-2023	Annual Growth (Average)	Standard Deviation
ENEA	19%	4%	18%	258%	12%	21%	84%	6%	14%
ENERGA	9%	2%	16%	283%	12%	17%	89%	6%	13%
PGE	1%	1%	11%	428%	15%	19%	155%	9%	17%
TAURON PE	33%	3%	16%	400%	16%	28%	167%	9%	18%
ZE PAK	-9%	5%	37%	404%	15%	26%	6%	3%	25%
POLENERGIA	5%	3%	21%	1620%	48%	111%	473%	28%	74%

Source: Own calculations.

In four of the analysed companies, the work efficiency based on number of employees indicator was growing the fastest, the work efficiency based on personnel costs indicator was second, while the VAICTM ratio was growing the slowest. In the case of ZE PAK, the VAICTM indicator grew faster than work efficiency based on personnel costs. This could be the result of the largest changes in the employment level in that company (Table 2), causing changes in the staff structure. A specific case is POLENERGIA, which has achieved improvements in work efficiency several times higher than in other companies according to work efficiency based on number of employees and work efficiency based on personnel costs indicators.

These differences in the picture of human capital efficiency in terms of various indicators may be related to the fact that the level of the VAICTM indicator in the Polish energy sector is determined by depreciation write-offs and CO₂ fees. The four leading companies in this respect have large assets related to coal energy, which require high depreciation charges. The lower result of ZE PAK results from the redemption of some assets during the analysed period, and the negative result for the entire analysed period of the POLENERGIA company results from the dominance of renewable energy sources as a source of generated energy (lack of coal assets and related depreciation write-offs and CO₂ fees).

Referring to the first hypothesis put forward in the article, changes in the considered measures of human capital efficiency and work efficiency in the analysed Polish energy companies in the years 2010-2023 were positive. In the case of work efficiency indicators based on sales revenues, the final improvement was mainly determined by recent years.

Figure 2 shows changes in the value of human capital per employee estimated according to VAICTM, taking into account changes in employment and the level of personnel costs. The inclusion in relation to a single employee is justified by the different initial employment levels in the analysed companies, as well as the personnel movements that occurred in them during the analysed period.

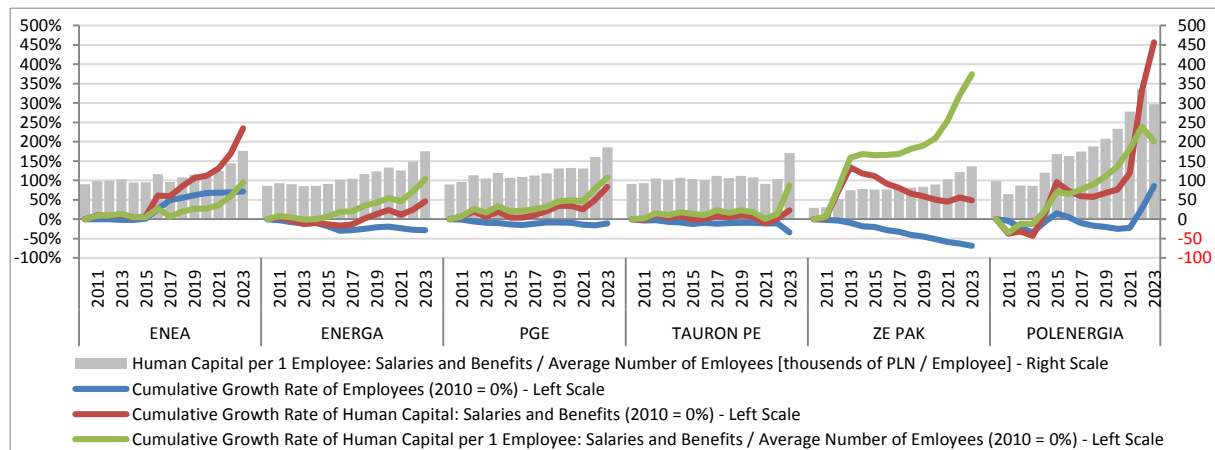


Figure 2. Human capital and its growth rate in the analysed Polish energy companies in 2010-2023.

Source: Own work.

All analysed companies recorded an increase in the value of human capital per employee. Significant differences in the list may result from several reasons, the most important of which is the change in employment levels. In the analysed period, companies that are extreme in this approach recorded an increase in employment by 86% (POLENERGIA) and a decrease in employment by 69% (ZE PAK). With such a large staff turnover, the VAICTM indicator based on salaries and benefits is determined to a greater extent by the structure of employees dismissed and hired, rather than changes in the value of human capital of employees employed in the company on a continuous basis. From this perspective, ZE PAK, while reducing employment by 69%, recorded an increase in the value of human capital per employee by 49%, which may indicate that the group of the most highly qualified employees remained in the company, while the group with lower than average qualifications (and lower salaries) was among those dismissed. On the other side of the ranking was TAURON PE, which, while reducing employment by 34%, recorded an increase in the value of human capital per employee by only 23%, which would indicate no improvement in the internal employment structure (loss of employees with at least medium qualifications).

One of the main reasons for changes in employment levels in individual companies is the structure of energy sources. At the beginning of the analysed period, ZE PAK based energy production on three power plants using brown coal (less calorific and more emissive than hard coal), one of which was shut down during the analysed period. POLENERGIA, where employment is growing, is by far the smallest company, produces energy based on renewable energy sources and partly gas, and does not use coal. Three of the four largest energy companies, producing electricity mainly from coal, show similar declines in employment levels. This indicates a gradual restructuring process. The exception in this group is ENEA, which recorded a significant increase in employment in the analysed period.

Table 2.

Changes in the value of human capital and the average number of employees in the analysed Polish energy companies in 2010-2023

	Human Capital: Salaries and Benefits			Average Number of Employees			Salaries and Benefits per Employee		
	Growth Rate 2010-2023	Annual Growth (Average)	Standard Deviation	Growth Rate 2010-2023	Annual Growth (Average)	Standard Deviation	Growth Rate 2010-2023	Annual Growth (Average)	Standard Deviation
ENEA	235%	11%	15%	72%	4%	8%	95%	6%	11%
ENERGA	46%	3%	10%	-28%	-2%	6%	103%	6%	8%
PGE	84%	5%	11%	-11%	-1%	3%	107%	6%	10%
TAURON PE	23%	2%	11%	-34%	-3%	8%	87%	6%	19%
ZE PAK	49%	5%	22%	-69%	-8%	5%	374%	14%	20%
POLENERGIA	457%	21%	43%	86%	8%	27%	200%	11%	21%

Source: Own calculations.

Referring to the second hypothesis put forward in the article, the analysed energy companies in the years 2010-2023 were characterized by different growth rates in the level of human capital. Although in the case of all surveyed entities there was an improvement over the period under study, in the case of the Tauron PE Group it was negligible, with additionally low variability. At the same time, it can be noted that in the case of most companies, the first half of the period under consideration (2010-2016) was characterized by a clearly lower dynamics of changes than the second half (2016-2023).

The article uses three different indicators to assess the efficiency of human capital, based on the same sources of financial data, but using different data. Table 3 presents the results of correlation and determination between human capital estimated using the VAICTM index and work efficiency indicators based on sales revenues. Calculations were made to determine whether the results obtained with the indicators used were similar.

Table 3.

Results of the Pearson linear correlation analysis between human capital estimated using the VAICTM index and work efficiency indicators in the analysed Polish energy companies in 2010-2023

	Work Efficiency Based on Number of Employees vs Human Capital Efficiency (VAIC TM)		Work Efficiency Based on Personnel Costs vs Human Capital Efficiency (VAIC TM)	
	Pearson's linear correlation coefficient	R ²	Pearson's linear correlation coefficient	R ²
ENEA	0.052	0.003	0.167	0.028
ENERGA	-0.157	0.025	0.217	0.047
PGE	-0.311	0.097	-0.327	0.107
TAURON PE	0.571*	0.326	0.512	0.262
ZE PAK	-0.017	0.000	0.651*	0.424
POLENERGIA	0.529	0.280	0.614*	0.377

* p < 0.05

Source: Own work.

The calculations show that in the analysed energy entities there is no clear correlation between the efficiency of human capital according to VAIC™ and work efficiency indicators. Therefore, it can be concluded that the indicators used in the article reflect changes in the analysed value (human capital efficiency) in a different way and an attempt can be made to determine which of them does it better.

The fourth hypothesis put forward in the article assumed that in the short term, especially in the event of economic shocks, work efficiency indicators are a better picture of changes in the efficiency of human capital than VAIC™. This formulation of the hypothesis resulted from literature studies. Table 4 contains a summary of average changes in the analysed indicators for all analysed companies in three-year periods.

Table 4.

Average changes in indicators of human capital efficiency and work efficiency in the distinguished periods calculated on the basis of annual growth rates in the analysed Polish energy companies in 2011-2023

		2011-2014	2014-2017	2017-2020	2020-2023	2011-2023
Human Capital Efficiency (VAIC™)	ENEA	7%	-1%	-2%	8%	3%
	ENERGA	14%	-1%	-11%	7%	2%
	PGE	-5%	5%	-7%	8%	0%
	TAURON PE	0%	1%	-1%	13%	3%
	ZE PAK	-22%	6%	-9%	45%	5%
	POLENERGIA	4%	5%	9%	-5%	3%
	Average	0%	2%	-3%	13%	3%
Work Efficiency Based on Number of Employees	ENEA	1%	-9%	13%	38%	11%
	ENERGA	3%	8%	2%	34%	12%
	PGE	4%	-5%	25%	29%	13%
	TAURON PE	-1%	-1%	5%	52%	14%
	ZE PAK	6%	3%	9%	43%	16%
	POLENERGIA	137%	55%	-4%	25%	53%
	Average	25%	9%	8%	37%	20%
Work Efficiency Based on Personnel Costs	ENEA	3%	-9%	6%	19%	5%
	ENERGA	6%	1%	-6%	22%	6%
	PGE	-3%	-3%	18%	15%	7%
	TAURON PE	-6%	-2%	7%	29%	7%
	ZE PAK	-20%	3%	5%	24%	3%
	POLENERGIA	83%	31%	-12%	10%	28%
	Average	11%	4%	3%	20%	9%
Real Work Efficiency Based on Number of Employees	ENEA	0%	-10%	9%	23%	6%
	ENERGA	2%	7%	-1%	17%	6%
	PGE	3%	-7%	23%	15%	8%
	TAURON PE	-2%	-1%	2%	31%	7%
	ZE PAK	5%	2%	6%	17%	8%
	POLENERGIA	135%	53%	-6%	16%	49%
	Average	24%	7%	6%	20%	14%

Source: Own work.

If we assume that the value and efficiency of human capital changes successively, a better picture of these changes is an indicator whose deviations from the trend are smaller. The data shows that human capital efficiency according to the VAIC™ model is characterized by lower variability than work efficiency indicators based on sales revenues, both in the long

and short periods. This also applies to changes in work efficiency based on number of employees in real terms (after taking into account price changes in the period 2011-2023 – last rows of Table 4). On the one hand, this indicates a better (more stable) estimation of changes in the efficiency of human capital by VAICTM both in the long and short term, also in conditions of economic shocks. This is definitely true from an accounting perspective. On the other hand, limiting ourselves only to the VAICTM indicator would be an oversimplification.

5. Discussion

The inspiration for taking up the topic of the article was the need to verify how the VAIC indicator and work efficiency indicators based on sales revenues reflect changes in the level and efficiency of human capital in the Polish energy sector.

None of the hypotheses presented in the article have been fully and positively verified. The first two hypotheses regarding a similar rate of growth in efficiency and the value of human capital in the entire sector and a better approximation of these changes in the short term by work efficiency indicators have not been fully confirmed by the available data. Differences in changes in efficiency and growth of human capital in individual companies are determined by several factors. Firstly, in the case of the Polish energy sector, the VAICTM indicator is largely influenced by the structure of fixed assets in the analysed companies (a large share in the added value of depreciation in companies with coal assets). Secondly, the analysed companies are at different stages of life. Five of them are in the maturity phase, they are large organizations based on the production of energy from coal, while the sixth company is in the growth phase and is based on the production of energy from renewable energy sources. Thirdly, the results obtained for the last year indicate that in conditions of high inflation, changes in the valuation of human capital are determined to a large extent by the bargaining power of trade unions, limited by the current financial situation of enterprises. Salary costs increase depending on the negotiated level of salary increases; as data shows, this process is delayed in Polish enterprises. Fourth, comparisons of the value of human capital are made difficult by significant changes in employment levels. The shareholding structure may also be a factor influencing the scale of employment changes. In four of the companies under consideration (apart from ZE PAK and POLENERGIA), the controlling interest is held by the state, which may slow down changes for energy security and social reasons, under pressure from trade unions that are strong in the sector (ZE PAK, however, carried out a very deep reduction in employment in the analysed period). "Private" companies (without a state controlling stake) achieved significantly faster improvement in indicators based on sales revenues generated by employees. Such results may indicate better personnel management by "private" companies, but it should be emphasized that they were also characterized

by the highest increase in salaries and benefits per employee (the improvement in indicators did not occur at the "expense" of employees). Fifthly, the reliability of data obtained both on the basis of VAICTM and work efficiency is limited by the state regulation of energy prices (limiting their increase, especially for households) (Prohorovs, 2022; Goldthau, Youngs, 2023).

The third hypothesis regarding the correlation between the estimates of changes in human capital performance according to the three applied approaches was not confirmed, even though both VAICTM and work efficiency indicators use similar financial values from the same source.

If the reliability of human capital efficiency indicators is assumed to be their stability, the hypothesis that VAICTM in the short term reflects changes in human capital efficiency worse than work efficiency indicators due to the shift in time of the effects of the company's personnel expenditures was not confirmed (Pulic, 2004; Andriessen, 2004). VAICTM turned out to be more stable both in the long term and in all three-year periods. Being more stable in accounting terms, it could be accepted as a better picture of changes in human capital efficiency. However, this conclusion is too far-reaching. If we compare both groups of indicators, it turns out that the increase in the work efficiency based on number of employees indicator is the highest in companies that have the lowest VAICTM indicators.

The contribution of the article to the existing literature is the repetition of research aimed at verifying the usefulness of the VAICTM model in estimating the efficiency of human capital and the confrontation of this indicator with work efficiency indicators.

The obtained results allow us to determine directions for further research. First of all, it is important to answer the question whether similar relationships between VAICTM and work efficiency indicators occur in other sectors of the Polish economy or whether they result only from the specificity of the energy sector (Diebolt, Hippe, 2019; Gennaioli et al., 2013). Since the indicators used in the article reflect changes in the analysed value (human capital efficiency) in different ways, one can attempt to determine which of them does it better. The answer to this question can be based, on one hand, on the valuation of the market value of enterprises and, on the other hand, on the analysis of internal labour resources in individual enterprises (their structure according to the level of education and work experience).

In the Polish energy sector, it is planned to separate coal assets (transferring them to a separate company under state supervision), which is to enable energy companies to reach for external sources of financing (most banks refuse to finance investments of enterprises using coal). Introducing this intention would allow for a more reliable comparison of the efficiency of human capital in Polish energy enterprises. It is advisable to repeat the study after a few years, after the end of inflationary processes, salaries adjustments that should be expected under pressure from trade unions (Ahlroth et al., 1997) and the separation of coal assets.

The article points to the specificity of the Polish coal-based electricity production sector, which will be abandoned in the Polish energy sector in a much longer time horizon than in other EU countries (about twenty years). The specificity resulting from the national context is the main limitation for generalizations of the results obtained during the study.

6. Summary

Comparing changes in the efficiency of human capital in the Polish energy industry is difficult due to a number of factors, the most important of which are high changes in the level and structure of employment (some companies increase employment, some reduce it) related to restructuring processes. This prevents reliable comparisons of human capital efficiency across entire companies and makes it difficult to estimate human capital per employee. Restructuring processes will intensify when (if) the state decides to separate coal assets from the structure of energy companies.

Referring to the results of the conducted research, attention is drawn to the ambiguous conclusions resulting from VAICTM and work efficiency indicators. Their comparison shows that the largest companies under state control achieve mostly the highest improvement in the efficiency of human capital measured by the VAICTM method. At the same time, they were outpaced in the case of the work efficiency based on number of employees indicator by "private" companies, one of which decided to undergo deep restructuring (and abandon the extraction of lignite and energy production from it within a few years), while the other one is growing based on investments in renewable energy sources. The basic conclusion resulting from this confrontation is the recommendation to use the VAICTM indicator and work efficiency indicators together when assessing the efficiency of human capital.

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References

1. Acemoglu, D., Gallego, F.A., Robinson, J.A. (2014). Institutions, human capital and development. *Annual Review of Economics*, 6(1), pp. 875-912.
2. Ahlroth, S., Björklund, A., Forslund, A. (1997). The Output Of The Swedish Education Sector. Review of Income and Wealth. *International Association for Research in Income and Wealth*, 43(1), pp. 89-104. <https://doi.org/10.1111/j.1475-4991.1997.tb00202.x>

3. Alataş, S., Çakir, M. (2016). The Effect of Human Capital on Economic Growth: A Panel Data Analysis. *Journal of Administrative Sciences*, 14(27), pp. 539-555.
4. Alekseeva, L., Azar, J., Giné, M., Samila, S., Taska, B. (2021). The demand for AI skills in the labor market. *Labour Economics*, Vol. 71, No. 6, 102002. <https://doi.org/10.1016/j.labeco.2021.102002>
5. Almendarez, L. (2013). Human Capital Theory: Implications for Educational Development in Belize and the Caribbean. *Caribbean Quarterly*, 59(3/4), *Special Issue: Building Sustainability in Belize: Through Education, Culture and Technology*, pp. 21-33.
6. Andriessen, D. (2004). *Making Sense of Intellectual Capital: Designing a Method for the Valuation of Intangibles*. Amsterdam, Nederland: Elsevier Butter-worth-Heinemann.
7. Angrist, N., Djankov, S., Goldberg, P.K., Patrinos, H.A. (2021). Measuring human capital using global learning. *Nature*, 592(7854), pp. 403-408. doi: <http://dx.doi.org/10.1038/s41586-021-03323-7>
8. Bakhsha, A., Afrazeh, A., Esfahani Pour, A. (2017). A Criticism on Value Added Intellectual Coefficient (VAIC) Model. *International Journal of Computer Science and Network Security*, 17(6), pp. 59-71.
9. Baran, J., Szpor, A., Witajewski-Baltvilks, J. (2020). Low-carbon transition in a coal-producing country: A labour market perspective. *Energy Policy*, 147, 111878. doi: <https://doi.org/10.1016/j.enpol.2020.111878>
10. Becker, G.S. (1993). *Human capital: a theoretical and empirical analysis with special reference to education*. Chicago, USA: University of Chicago Press.
11. Bodman, P., Le, T. (2013). Assessing the roles that absorptive capacity and economic distance play in the foreign direct investment productivity growth nexus. *Applied Economics*, 45(8), pp. 1027-1039. doi: <https://doi.org/10.1080/00036846.2011.613789>
12. Bornemann, M., Knapp, A., Schneider, U., Sixl, K.I. (1999). Holistic measurement of intellectual capital. International Symposium: Measuring and Reporting Intellectual Capital: Experiences. *Issues and Prospects Conference*, Amsterdam, Nederland, 9-10 June. Retrieved from: www.oecd.org/dataoecd/16/20/1947871.pdf, 2.05.2023.
13. Buessellmann, S. (2009). *Human Capital and Economic Growth, Analyzing the Impact of Skilled Labour on Economic Prosperity*. Saarbruecken, Germany: VDM Verlag.
14. Buzavaite, M., Korsakiene, R. (2019). Human Capital and the Internationalisation of SMEs: A Systemic Literature Review. *Entrepreneurial Business and Economics Review*, 7(3), pp. 125-142. doi: <https://doi.org/10.15678/EBER.2019.070307>
15. Capros, Q., Paroussos, L., Fragkos, Q., Tsani, S., Boitier, B., Wagner, F., Busch, S., Resch, G., Blesl, M., Bollen, J. (2014). Description of models and scenarios used to assess European decarbonisation pathways. *Energy Strategy Reviews*, 2, pp. 220-230. doi: <https://doi.org/10.1016/j.esr.2013.12.008>

16. Castelló-Climent, A. (2019). The Age Structure of Human Capital and Economic Growth. *Oxford Bulletin of Economics and Statistics*, 81(2), pp. 394-411. doi: <https://dx.doi.org/10.1111/obes.12274>
17. Chan, K.H. (2009). Impact of intellectual capital on organisational performance: An empirical study of companies in the Hang Seng Index (Part 2). *Learning Organization*, 16(1), pp. 22-39. doi: <https://doi.org/10.1108/09696470910927650>
18. Chen, J., Zhu, Z., Xie, H.Y. (2004). Measuring intellectual capital: a new model and empirical study. *Journal of Intellectual Capital*, 5(1), pp. 195-212. doi: <https://doi.org/10.1108/14691930410513003>
19. CIPD (2017). *Human capital theory: assessing the evidence for the value and importance of people to organisational success – Technical report, May 2017*. Ulster University, UK. Retrieved from: https://www.cipd.org/globalassets/media/knowledge/knowledge-hub/reports/human-capital-theory-assessing-the-evidence_tcm18-22292.pdf, 21.05.2023.
20. Dakhli, M., De Clercq, D., (2004). Human capital, social capital, and innovation: a multi-country study. *Entrepreneurship & Regional Development*. Vol. 16, No. 2, pp. 107-128. doi:10.1080/08985620410001677835
21. Dańska-Borsiak, B. (2023). Human capital convergence in European NUTS 2 regions. *Equilibrium – Quarterly Journal of Economics and Economic Policy*, 18(2), pp. 367-392. doi: <https://doi.org/10.24136/eq.2023.011>
22. Davenport, T.O. (1999). *Human Capital: What It Is and Why People Invest It*. San Francisco, USA: Jossey-Bass Publishers.
23. Diebolt, C., Hippe, R. (2019). The long-run impact of human capital on innovation and economic development in the regions of Europe. *Applied Economics*, 51(5), pp. 542-563. doi: <https://doi.org/10.1080/00036846.2018.1495820>
24. Edvinsson, L., Malone, M. (1997). *Intellectual Capital: Realizing Your Company's True Value by Finding Its Hidden Roots*. New York, USA: Harper Collins Publishers.
25. Edvinsson, L., Sullivan, P. (1996). Developing a model of managing intellectual capital. *European Management Journal*, 14(4), pp. 356-364. doi: [https://doi.org/10.1016/0263-2373\(96\)00022-9](https://doi.org/10.1016/0263-2373(96)00022-9)
26. European Commission (2020). Sustainable Europe Investment Plan: European Green Deal Investment Plan. *The European Economic And Social Committee And The Committee Of The Regions*. Retrieved from: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0021>, 15.05.2022.
27. Feng, A., Graetz, G., (2020). Training Requirements, Automation, and Job Polarisation. *The Economic Journal, Royal Economic Society*, 130(631), pp. 2249-2271. <https://doi.org/10.1093/ej/ueaa044>
28. Firer, S., Williams, S.M. (2003). Intellectual capital and traditional measures of corporate performance. *Journal of Intellectual Capital*, 4(3), pp. 348-60. doi: <https://doi.org/10.1108/14691930310487806>

29. Gan, K., Saleh, Z. (2008). Intellectual capital and corporate performance of technology-intensive companies: Malaysia evidence. *Asian Journal of Business and Accounting*, 1(1), pp. 113-130.
30. Gennaioli, N., La Porta, R., Lopez-de-Silanes, F., Shleifer, A. (2013). Human capital and regional development. *The Quarterly Journal of Economics*, 128(1), pp. 105-164. doi: <https://doi.org/10.1093/qje/qjs050>
31. Gibbons R., Katz, L.F., Lemieux, T., Parent, D. (2005). Comparative Advantage, Learning, and Sectoral Wage Determination. *Journal of Labour Economics*, 23(4), pp. 681-724. doi: <https://doi.org/10.1086/491606>
32. Goldthau, A.C., Youngs, R., (2023). The EU Energy Crisis and a New Geopolitics of Climate Transition. *Journal of Common Market Studies*, 61, pp. 111-124, doi: <https://doi.org/10.1111/jcms.13539>
33. Habib, M., Abbas, J., Noman, R., (2019). Are human capital, intellectual property rights, and research and development expenditures really important for total factor productivity? An empirical analysis. *International Journal of Social Economics*, 46(6), pp. 756-774. doi: <https://doi.org/10.1108/IJSE-09-2018-0472>
34. Hanushek, E.A., Woessmann, L. (2008). The Role of Cognitive Skills in Economic Development. *Journal of Economic Literature*, 46(3), pp. 607-668. doi: <https://doi.org/10.1257/jel.46.3.607>
35. Huggins, R., Prokop, D., Thompson, P., (2017). Entrepreneurship and the determinants of firm survival within regions: human capital, growth motivation and locational conditions. *Entrepreneurship & Regional Development*, 29(3-4), pp. 357-389, doi:10.1080/08985626.2016.1271830
36. Iazzolino, G., Laise, D. (2013). Value added intellectual coefficient (VAIC): A methodological and critical review. *Journal of Intellectual Capital*, 14(4), pp. 547-563. doi: <https://doi.org/10.1108/JIC-12-2012-0107>
37. Iazzolino, G., Laise, D., Migliano, G. (2014). Measuring value creation: VAIC and EVA. *Measuring Business Excellence*, 18(1), pp. 501-514. doi: <https://doi.org/10.1108/MBE-10-2013-0052>
38. Iazzolino, G., Migliano, G., Dattilo, M.I. (2019). The impact of Intellectual Capital on Firms' Characteristics: an empirical analysis on European listed manufacturing companies. *International Journal of Industrial Engineering and Management*, 10(3), pp. 219-237. doi: <http://doi.org/10.24867/IJIE-2019-3-242>
39. Jorgenson, D.W., Fraumeni, B.M. (1989). The accumulation of human and non-human capital, 1948-1984. In: R.E. Lipsey, H.S. Tice (Eds.), *The Measurement of Savings, Investment and Wealth* (pp. 227-282). Chicago: University of Chicago Press.
40. Kraay, A. (2018). Methodology for a World Bank Human Capital Index. *Policy Research Working Paper*, 8593. Washington: World Bank. Retrieved from <https://openknowledge.worldbank.org/handle/10986/30466>, 4.05.2023.

41. Kuzior, A., Arefieva, O., Kovalchuk, A., Brożek, P., Tytykalo, V. (2022). Strategic Guidelines for the Intellectualization of Human Capital in the Context of Innovative Transformation. *Sustainability*, 14(19), 11937. doi: <https://doi.org/10.3390/su141911937>
42. Laing, G., Dunn, J., Hughes-Lucas, S. (2010). Applying the VAIC model to Australian hotels. *Journal of Intellectual Capital*, 11(3), pp. 269-283. doi: <https://doi.org/10.1108/14691931011064545>
43. Laroche, M., Mérette, M., Ruggeri, G.C. (1999). On the Concept and Dimension of Human Capital in a Knowledge-Based. *Canadian Public Policy*, 25(1), pp. 87-100.
44. Lee, J-W., Lee, H. (2016). Human capital in the long run. *Journal of Development Economics*, 122, pp. 147-169. doi: <http://dx.doi.org/10.1016/j.jdeveco.2016.05.006>
45. Lenkei, B. (2019). *Essays on Human Capital*. London: Middlesex University.
46. Lepak, D.P., Snell, S.A. (1999). The Human Resource Architecture: Toward a Theory of Human Capital Allocation and Development. *The Academy of Management Review*, 24(1), pp. 31-48. doi: <https://doi.org/10.2307/259035>
47. Lerro, A., Linzalone, R., Schiuma, G. (2014). Managing intellectual capital dimensions for organizational value creation. *Journal of Intellectual Capital*, 15(3), pp. 350-361. doi: <https://doi.org/10.1108/jic-05-2014-0063>
48. Lim, S.S., Updike, R.L., Kaldjian, A.S., Barber, R.M., Cowling, K., York, H., Friedman, J., Xu, R., Whisnant, J.L., Taylor, H.J., Leever, A.T., Roman, Y., Bryant, M.F., Dieleman, J., Gakidou, E., Murray, C.J.L. (2018). *Measuring human capital: a systematic analysis of 195 countries and territories*. Seattle: Institute for Health Metrics and Evaluation, University of Washington. doi: [http://dx.doi.org/10.1016/S0140-6736\(18\)31941-X](http://dx.doi.org/10.1016/S0140-6736(18)31941-X)
49. Maditinos, D., Chatzoudes, D., Tsairidis, C., Theriou, T. (2011). The impact of intellectual capital on firms' market value and financial performance. *Journal of Intellectual Capital*, 12(1), pp. 132-151. doi: <https://doi.org/10.1108/14691931111097944>
50. Marr, B., Moustaghfir, K. (2005). Defining Intellectual Capital: A Three-dimensional Approach. *Management Decision*, 43(9), pp. 1114-1128. doi: <https://doi.org/10.1108/00251740510626227>
51. Marr, B., Schiuma, G., Neely, A. (2004). Intellectual capital – defining key performance indicators for organizational knowledge assets. *Business Process Management Journal*, 10(5), pp. 551-569. doi: <https://doi.org/10.1108/14637150410559225>
52. Martínez-Torres, M.R. (2006). A Procedure to Design a Structural and Measurement Model of Intellectual Capital: An Exploratory Study. *Information & Management*, 43(5), pp. 617-626. doi: <https://doi.org/10.1016/j.im.2006.03.002>
53. Marzo, G. (2022). A theoretical analysis of the value added intellectual coefficient (VAIC). *Journal of Management and Governance*, 26(2), pp. 551-577. doi: <https://doi.org/10.1007/s10997-021-09565-x>
54. Mayo, A. (2001). *The Human Value of the Enterprise Valuing People as Assets-Monitoring, Measuring, Managing*. London: Nicholas Brealey Publishing.

55. McConnell, C.R. (1984). *Economics*. New York/St. Louis: McGraw-Hill.
56. Meles, A., Porzio, C., Sampagnaro, G., Verdoliva, V. (2016). The impact of intellectual capital efficiency on commercial bank performance: Evidence from the US. *Journal of Multinational Financial Management*, 36(1), pp. 64-74. doi: <https://doi.org/10.1016/j.mulfin.2016.04.003>
57. Milost, F. (2005). Dynamic monetary model of intellectual capital evaluation. *Proceedings of the 6th International Conference of the Faculty of Management*. Koper Congress Centre Bernardin, Slovenia, 24-26 November.
58. Mulliqi, A., Adnett, N., Hisarciklilar, M., Rizvanolli, A. (2018). Human Capital and International Competitiveness in Europe, with Special Reference to Transition Economies. *Eastern European Economic*, 56(6), pp. 541-563. doi: <https://dx.doi.org/10.1080/00128775.2018.1502612>
59. Nabi, M.N., Gao, Q., Rahman, M.T., Britton, S.O., Islam, M.M. (2020). Intellectual Capital and Corporate Performance: Evidence From Banking Industry of Bangladesh. *International Journal of Human Resource Studies*, 10(1), pp. 234-259. doi: <https://doi.org/10.5296/ijhrs.v10i1.16146>
60. Nawrocki, T.L., Jonek-Kowalska, I. (2023). Efficiency of Polish Energy Companies in the Context of EU Climate Policy. *Energies*, 16, 826. doi: <https://doi.org/10.3390/en16020826>.
61. Nazari, J.A., Herremans, I.M. (2007). Extended VAIC Model: Measuring Intellectual Capital Components. *Journal of Intellectual Capital*, 8, pp. 595-609. doi: <https://doi.org/10.1108/14691930710830774>
62. Nelson, R., Phelps, E. (1966). Investment in humans, technological diffusion, and economic growth. *The American Economic Review*, 56(1/2), pp. 69-75. doi: <https://www.jstor.org/stable/1821269>
63. Nilsson, C., Ford, D. (2004). Introducing intellectual potential – the case of Alfa Laval. *Journal of Intellectual Capital*, 5(3), pp. 414-425. doi: <https://doi.org/10.1108/14691930410550372>
64. OECD (1998). *Human Capital Investment*. Retrieved from: <https://doi.org/10.1787/9789264162891-en>, 2.05.2023.
65. Østergaard, A., Marinova, S.T. (2018). Human Capital in the Entrepreneurship Ecosystem. *International Journal of Entrepreneurship and Small Business*, 35(3), pp. 371-390. doi: <https://doi.org/10.1504/IJESB.2018.095907>
66. Ozkan, N., Cakan S., Kayacan, M. (2017). Intellectual capital and financial performance: A study of the Turkish Banking Sector. *Borsa Istanbul Review*, 17(3), pp. 190-198. doi: <https://doi.org/10.1016/j.bir.2016.03.001>
67. Pach-Gurgul, A., Ulbrych, M. (2019). Progress of V4 Countries towards the EU's Climate and Energy Targets in the Context of the Energy Supply Security Improvement. *Entrepreneurial Business and Economics Review*, 7(2), pp. 175-197. doi: <https://doi.org/10.15678/EBER.2019.070210>

68. Pap, E., Petković, M., Simićević, A. (2021). Measuring distribution of intellectual capital components contribution: French context. *The European Journal of Applied Economics*, 18(1), pp. 1-14. doi: <https://doi.org/10.5937/EJAE18-28628>
69. Pritchett, L. (2001). Where has all the education gone? *World Bank Economic Review*, 15(3), pp. 367-391.
70. Prohorovs, A. (2022). Russia's War in Ukraine: Consequences for European Countries' Businesses and Economies. *Journal of Risk and Financial Management*, 15(7), 295. <https://doi.org/10.3390/jrfm15070295>
71. Pulic, A. (1998). Measuring the performance of intellectual potential in the knowledge economy. *2nd McMaster World Congress on Measuring and Managing Intellectual Capital by the Austrian Team for Intellectual Potential*. Retrieved from: <https://www.academia.edu/8959823>, 2.05.2023.
72. Pulic, A. (2000a). MVA and VAIC™ Analysis of Randomly Selected Companies from FTSE 250. *Austrian Intellectual Capital Research Centre*. Graz, Austria/ London: UK. Retrieved from: <http://www.measuring-ip.at/Papers/ham99txt.htm>, 2.05.2023.
73. Pulic, A. (2000b). VAIC – an accounting tool for IC management. *International Journal of Technology Management*, 20, pp. 702-714. doi: <https://doi.org/10.1504/IJTM.2000.002891>
74. Pulic, A. (2004). Intellectual capital – does it create or destroy value? *Measuring Business Excellence*, 8(1), pp. 62-68.
75. Pulic, A. (2008). *The Principles of Intellectual Capital Efficiency*. Retrieved from: <https://www.scinapse.io/papers/2371185822>, 2.05.2023.
76. Puntillo, P. (2009). Intellectual capital and business performance. Evidence from Italian banking industry. *Electronic Journal of Corporate Finance*, 4(12), pp. 97-115.
77. Queirós, A.S.S., Teixeira, A.A.C. (2016). Economic Growth, Human Capital and Structural Change: An Empirical Analysis. *Research Policy*, 45, pp. 1636-1648.
78. Roos, J., Ross, G., Dragonetti, N.C., Edvinsson, L. (1997). *Intellectual Capital. Navigation the New Business Landscape*. Basingtoke: Palgrave Macmillan.
79. Rossi, F. (2020). Human Capital and Macro-Economic Development: A Review of the Evidence. *The World Bank Research Observer*, 35(4), pp. 227-262. doi: 10.1093/wbro/lkaa002
80. Schultheiss, T., Pfister, C., Gnehm, A-S., Backes-Gellner, U., (2023). Education expansion and high-skill job opportunities for workers: Does a rising tide lift all boats? *Labour Economics*, 82(C), pp. 1-23. doi: <https://doi.org/10.1016/j.labeco.2023.102354>
81. Schultz, T.W. (1961). Investment in human capital. *American Economic Review*, 51(1), pp. 1-17.
82. Segu, Z., Natoli, R. (2012). Human capital: The history, measurement and impact on nations from an economic perspective. *International Journal of Value Chain Management*, 6(1), pp. 61-77. doi: <https://doi.org/10.1504/IJVC.2012.045158>

83. Sheveleva, L., Jones, M., Harris, I. (2023). It does not matter how hard you work: The importance of task allocation for worker productivity. *Economics Letters*, 227(C), pp. 1-4. doi: <https://doi.org/10.1016/j.econlet.2023.111115>
84. Shiu, H. (2006). The application of the value added intellectual coefficient to measure corporate performance: evidence from technological firms. *International Journal of Management*, 23(2), pp. 356-65.
85. Škare, M., Lacmanović, S. (2015). Human capital and economic growth: a review essay. *Amfiteatru Economic Journal*, 17(39), pp. 735-760.
86. Son, H.H. (2010). *Human Capital Development*. Retrieved from: <https://www.adb.org/sites/default/files/publication/28427/economics-wp225.pdf>, 4.05.2023.
87. Ståhle, P., Ståhle, S., Aho, S. (2011). Value Added Intellectual Coefficient (VAIC): a critical analysis. *Journal of Intellectual Capital*, 12(4), pp. 247-268. doi: <https://doi.org/10.1108/14691931111181715>
88. Stewart, T.A. (1997). *Intellectual capital: the new wealth of organizations*. New York: Doubleday Dell Publishing Group.
89. Storberg-Walker, J. (2004). *Towards a Theory of Human Capital Transformation Through Human Resource Development*. Retrieved from: <https://files.eric.ed.gov/fulltext/ED492359.pdf>, 2.05.2023.
90. Swoczyna, B. (2024). *Węglowe podsumowanie roku 2023*. Retrieved from: <https://energy.instrat.pl/weglowe-podsumowanie-2024-02-22/>, 18 August 2024.
91. Szczepankiewicz, E.I.; Mućko, Q. (2016). CSR Reporting Practices of Polish Energy and Mining Companies. *Sustainability*, 8, 126. doi:10.3390/su8020126
92. Tan, H.P., Plowman, D., Hancock, P. (2007). Intellectual capital and financial returns of companies. *Journal of Intellectual Capital*, 8(1), pp. 76-94. doi: <https://doi.org/10.1108/14691930710715079>
93. Unger, J.M., Rauch, A., Frese, M., Rosenbusch, N. (2011). Human capital and entrepreneurial success: a meta-analytical review. *Journal of Business Venturing*, 26(3), pp. 341-358.
94. Urząd Regulacji Energetyki (2024). *Charakterystyka rynku energii elektrycznej*. Retrieved from: <https://www.ure.gov.pl/pl/energia-elektryczna/charakterystyka-ryнку/10372,2021.html>, 4 August 2024.
95. van Beurden, Q., Goessling, T. (2008). The worth of values - A literature review on the relation between corporate social and financial performance. *Journal of Business Ethics*, 82, pp. 407-424. doi: <https://doi.org/10.1007/s10551-008-9894-x>
96. Wang, H, Hao, L., Wang, W., Chen, X. (2023). Natural resources lineage, high technology exports and economic performance: RCEP economies perspective of human capital and energy resources efficiency. *Resources Policy*, 87A, 104297. doi: <https://doi.org/10.1016/j.resourpol.2023.104297>

97. Wielechowski, M., Cherevyk, D., Czech, K., Kotyza, P., Grzęda, Ł., Smutka, L. (2021). Interdependence between human capital determinants and economic development: K-means regional clustering approach for Czechia and Poland. *Entrepreneurial Business and Economics Review*, 9(4), pp.173-194. <https://doi.org/10.15678/EBER.2021.090411>
98. Wosiek, M. (2020). Rural–urban divide in human capital in Poland after 1988. *Oeconomia Copernicana*, 11(1), pp. 183-201. doi: <https://doi.org/10.24136/oc.2020.008>
99. Young, C.S., Su, H.Y., Fang, S.C., Fang, S.R. (2009). Cross-country comparison of intellectual capital performance of commercial banks in Asian economics. *The Service Industries Journal*, 29(11), pp. 1565-1579. doi: <https://doi.org/10.1080/02642060902793284>
100. Zhang, H., Liu, O., Lu, D., Wang, X., Fan, H. (2023). Sustainable development perspective of linking natural re-sources and human capital development: An overview of resources utilization. *Resources Policy*, 86B, 104097. doi: <https://doi.org/10.1016/j.resourpol.2023.104097>
101. Zieliński, M., Adamska, M. (2022). ESG Assessment from the Perspective of the Management Board and Trade Unions on the Example of the Opole Power Plant. *Energies*, 15, 8066. doi: <https://doi.org/10.3390/en15218066>.

THE ESSENCE OF THE PROCESS OF ORGANIZING AND MANAGING TOURIST EXPENSES OF CRUISE SHIP PASSENGERS CASE STUDY SEAPORT IN KOŁOBRZEG

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Aim: The aim of the article was to present the essence of the processes of organizing and managing the estimation of tourist expenses made by cruise ship passengers and their impact on the local and national economy. The research was limited to the port and the city of Kołobrzeg.

Design/methodology/approach: In order to achieve the aim of the article, research was required to conduct research using a diagnostic survey method. The impact of expenditure on the local and national economy was estimated on the basis of the input-output method using the Flegg location coefficient.

Results: In the research process, five groups of tourists were identified with different levels of spending. By demonstrating that tourist expenditure depends on the number of tourists, nationality, length of stay in the city, type of tourism and structure of expenditure. It was pointed out that tourists can have an impact on the local and national economy.

Research limitations/implications: Future research in this area should clarify the premises for choosing the port of Kołobrzeg as the place of stay. In particular, determine what impact the possibility of using tourist cruises has on decisions. The research should cover other seaports where tourist cruises are carried out. The area of research should also be narrowed down to smaller territorial units.

Practical implications: The results of the research may be useful for owners of tourist vessels and port/city authorities. In order to organize and manage expenditures on tourism, the promotion of tourist services should be particularly addressed to foreign and domestic tourists from the wider environment, for whom cruises are the main attraction.

Social implications: Managing and organizing tourist expenses can improve the financial situation of tourist vessel owners. Tax revenues may increase. Tourists can become a carrier of promotion about the city and the port.

Originality/value: The research allowed for the identification of individual tourist groups in the process of organizing and managing tourist expenses. Determination of the amount of expenditure and the impact on the economy of the region and the country.

Keywords: processes of organization and management, tourist expenditures, research and analysis, input-output method.

Category of work: scientific work.

1. Introduction

As the available literature indicates, tourist cruises are becoming more and more popular around the world, which is reflected in passenger traffic statistics (CLIA, 2024). Also in Poland, cruise tourism is gaining in importance with the number of passengers at the level of nearly 1 million (GUS, 2019b; Central Statistical Office, 2023b). It is grown both in ports of fundamental importance to the national economy and in smaller local ports. Tourist cruises provide benefits not only for shipowners, but also for the local and national economy. Therefore, also in this case, there is a need to examine organizational and management processes in the economic aspect, especially in relation to the demand side. However, the amount of tourist spending has not been studied so far. Taking into account the above circumstances, the aim of the article is to discuss the essence of the process of organizing and managing tourist expenses made by cruise ship passengers and their impact on the local and national economy. The research focuses on expenditures carried out in the city of Kołobrzeg. However, they do not take into account the expenses related to the sea cruise itself, i.e. the purchase of a ticket. The research was limited to the port of Kołobrzeg, which is the leader in tourist cruises among small seaports (GUS, 2019b; Central Statistical Office, 2023b). The city itself is one of the most popular health resorts in Poland with numerous tourist attractions (Oleszczyk, Dominiak, 2021).

Expenditures made in the local economy were determined on the basis of a survey. Their impact on the local economy was determined using the input-output method. The Koszalin subregion was considered to be the local economy. As far as the structure of expenditure is concerned, five most important groups have been distinguished, i.e. expenditure on accommodation, food, transport, purchase of goods and other services.

It is important to emphasize that research on cruise tourism is not a frequently discussed research topic. According to Vayá et al. (2017), there are few studies that attempt to determine the volume of tourist spending and its economic importance. Frequently cited authors on cruise tourism include Dwyer and Forsyth (1998), Braun et al. (2002), Brida et al. (2012), BREA (2013), Worley and Akehurst (2013), Papadopoulou and Sambracos (2014), CERTeT Bocconi (2015), Chang et al. (2016), Vayá et al. (2017), Artal-Tur et al. (2018). On the other hand, the national literature lacks studies on the issues of cruise tourism and the issue of organization and management of tourist expenses.

The article consists of four parts. In the first part, a review of the literature was made. The focus is on the most important studies that were often cited by the authors. Attention was paid to the method of estimating tourist expenses. The second part discusses and justifies the choice of research methods. The next part presents the results of the research, i.e. the method of estimating tourist expenditure and its economic importance. The fourth part interprets the results, focusing on the factors influencing the volume of tourist expenditure and the impact on

the local and national economy. Indicating further areas of transformation in the organizational and management scope, covering not only the sphere of expenses, but the entire process of functioning of the cruise market.

2. Literature review

It is generally recognized that the first authors who comprehensively dealt with the organization and management of expenses in the field of tourist cruises were Dwyer and Forsyth (1998). They distinguished the expenses incurred by passengers and operators of maritime vessels. The first group of costs includes expenses related to the arrival of tourists at the home port (transport, accommodation, meals, purchases of goods and services, tourist attractions), a sea cruise (ticket price, tourist attractions) and stay in ports of call (food, shopping, tourist attractions). On the other hand, the operators' costs are related to the services provided to the marine vessel and the expenses incurred by the crew members. The former include, among others, the costs of repairs and maintenance, navigation services (for the entry/exit of the vessel to/from the port), port fees (parking and passenger), purchase of fuel and energy carriers and collection of pollution, marketing, crew salaries. On the other hand, the expenses of the crew members are related to transport, accommodation, food, shopping and tourist attractions. According to the authors, among the most commonly used methods in research on cruise tourism are the input-output method and the CGE general equilibrium model. Based on the developed methodology, the authors conducted research on cruise tourism in Australia.

Braun et al. (2002) investigated the importance of cruise tourism at the Port of Canaveral, Florida, USA. In their research, they distinguished expenses incurred by sea vessels, passengers and crew members. They determined the direct effects by means of a survey. In order to depict the economic importance of passenger spending, they used the regional input-output model.

BREA (2013) conducted research for the Port of Victoria in Canada. In their research, they took into account the expenses incurred by passengers, crew members and maritime vessels. Direct tourist expenses were determined by means of a survey. They then used a regional input-output table to estimate the impact of passenger spending on British Columbia's regional economy.

Worley and Akehurst (2013) identified the economic importance of cruise tourism in 11 New Zealand ports. They used information obtained from seaport authorities and national accounts. They then calculated the indirect impact of cruise tourism on the regional economy using the input-output method.

Chang et al. (2015) investigated the economic importance of cruise tourism of the port of Incheon in South Korea. The authors investigated the direct impact using a survey method. Indirect impact, on the other hand, using the regional input-output table. The article emphasizes

the disproportions in economic effects occurring between the home port and the port of call, in favor of the former.

Vayá et al. (2017) determined the importance of tourist cruises to the economy of Catalonia. The study included the expenses of tourists, crew members and passenger ships. The direct effect was determined on the basis of a survey, while the indirect effect was determined on the basis of the regional input-output table.

On the other hand, Artal-Tur et al. (2018) made an economic assessment of cruise tourism based on the activities of the seaport of Cartagena. They distinguished expenses incurred by passengers, crew members and sea vessels. The assessment of the direct effect was based on data obtained from surveys and other primary sources of information, i.e. a database of enterprises, commercial registers. The indirect effect was determined using the regional input-output table for the Region of Murcia. In addition, the authors drew attention to the diverse range of benefits for home ports and ports of call.

The above description of the methodology of the study of cruise tourism revealed three categories of expenses that are incurred by: passengers, crew members and marine vessels. The above-mentioned expenses are included in the direct impact of cruise tourism on the economy, and their estimation is most often carried out using the survey method. On the other hand, when determining the impact of expenditure on the economy (indirect effect), the input-output method is most often used. However, the CGE general equilibrium model is also applicable. The second observation is the diverse range of benefits between the home port and the port of call. The beneficiary of the economic effects is primarily the home port.

This article focuses on the study of expenses incurred by passengers. Tourist cruises take place without calling at ports, so the port of Kołobrzeg is the home port and all expenses are concentrated in the local economy.

3. Method and sources of information

In this article, the method of a diagnostic survey was used. Surveys were conducted among passengers of tourist vessels. 384 tourists participated in the survey. The research sample was determined in a statistical manner, which increased its representativeness. The research was carried out during tourist cruises in June-August 2023. Based on the conducted research, five groups of tourists were identified. The largest group were domestic tourists, for whom cruises were one of many attractions (with a 56% share). A smaller group were foreign tourists with a 25% share. Domestic tourists, for whom passenger cruises were the main attraction from the distant environment, constituted 8%, and from the closer otrange 6%. The last group were local tourists with a 5% share. The research results allowed for determining the reasons for choosing Kołobrzeg as a tourist destination, the length of stay in the city and the size of the

household, which had an impact on the size and structure of expenditure. It was also the basis for determining the economic significance of tourist expenditure.

The input-output method was used to determine the impact of expenditure on the local and national economy. As already mentioned, research on the economic importance of cruises mainly uses two methods, i.e. the CGE general equilibrium models and the input-output method. The choice of the input-output method was dictated by its simplicity, the possibility of using it on a local scale (NUTS 3) and the complexity of the results. Calculations can be based on available models or made using an excel spreadsheet. On the other hand, the CGE general equilibrium model is more complicated and often requires the involvement of a multidisciplinary research team. In addition, it is used for research on a national and international scale (Kahouli, Martin, 2018; Connolly, 2020; Jenniches, 2018)

The input-output method is based on sectoral dependencies occurring in the economy. It allows to determine the impact of demand, e.g. tourist spending, on economic quantities such as: global value, value added, employment, and the amount of tax revenues (Coto-Millán et al., 2010; Danielis, Gregori, 2013; Santos et al., 2018). This article presents only the impact of tourist expenditure on the global value using multipliers. The formula for determining the impact of expenditure on the local and national economy is the formula:

$$X_{indi} = (I - A_{ij})^{-1}Y \quad (1)$$

Where:

X_{indi} – output in sectors that are a source of supply for tourism service providers,

I – Identity matrix,

$A_{ij} = \frac{x_{ij}}{x_i}$ – technical coefficients of intermediate consumption, where x_{ij} – flow from the i -th to the j -th branch,

Y – demand for tourist services.

The use of the input-output method is based on the data contained in the inter-branch flow tables published in Poland at 5-year intervals (the latest available version presents data for 2015) (CSO, 2019a). The Central Statistical Office in Poland publishes tables of input-output flows at the national level, which is associated with the need to adapt them to the regional dimension. Regionalization allows you to determine the self-sufficiency of the reference area and is the most difficult task related to the use of the input-output method. Before regionalization, the table of input-output flows was aggregated from 98 to 19 divisions corresponding to the PKD 2007 section. The procedure for narrowing down the table was dictated by the availability of statistical data at the level of the Koszalin subregion. In addition, too much disaggregation affects the complexity of the model, making it difficult to interpret the results.

The regionalization of the national table was carried out on the basis of the Flegg location coefficient expressed by the formula (Flegg, Webber, 1997; Flegg, Tohmo, 2010):

$$FLQ_{ij} \times [(1 +) \equiv CILQ_{ij} \log_2 \frac{TRE}{TNE}]^{\delta} \quad (2)$$

Where:

FLQ_{ij} – Flegg's location coefficient.

TRE – employment in the region's economy (in all sectors).

TNE – employment in the national economy (in all sectors).

$$CILQ_{ij} = \frac{SLQ_i}{SLQ_j} = \frac{RE_i/NE_i}{RE_j/NE_j}$$

Where:

RE_i - regional employment in the selling sector,

NE_i - domestic employment in the selling sector,

RE_j - regional employment in the buying sector,

NE_j - domestic employment in the buying sector,

δ - the delta parameter, the value of which is in the range ($0 < \delta < 1$).

Location coefficients are most often used in the regionalization of the national table, and among them, the Flegg coefficient is the most accurate in determining the self-sufficiency of regions. The value of the key parameter in the formula δ was adopted on the basis of Flegg and Tohmo studies for Finnish regions (Flegg, Webber, 2000). As a result, the regression function used to determine the value of the parameter δ was estimated:

$$\ln \delta = -1.8379 + 0.33195 \ln R \quad (3)$$

Substituting the added value for the "R" parameter, the value of the δ parameter for the Koszalin subregion was estimated, which amounted to 0.2224.

4. Results

264,728 passengers took part in tourist cruises in 2023, which can be divided into five groups (Table 1). Tourists from abroad accounted for 25% of passengers, i.e. 66,182 people. They were mainly tourists from Germany and Scandinavian countries. As far as the subjective structure is concerned, it was most often a family consisting of two or three people. For foreign tourists, cruises were one of the many attractions of choosing Kołobrzeg as their place of stay. Hence, it was assumed that one day of stay in Kołobrzeg is associated with tourist cruises. The average expenditure of a foreign tourist related to sea cruises amounted to PLN 393 (Table 2). Expenses related to accommodation (PLN 161) (41%) and meals (PLN 129) (33%) dominated. Foreign tourists spent much less funds on transport (PLN 70) (18%) and the purchase of goods PLN 22 (6%) and other services PLN 11 (3%).

Table 1.*Groups of tourists enjoying tourist cruises in Kołobrzeg in 2023*

Size	Groups of tourists					Together
	Foreign tourists	Domestic tourists cruise one of the many attractions	Domestic tourists further surroundings	Domestic tourists closer surroundings	Local tourists	
Number of tourists	66 182	148 248	21 178	15 884	13 236	264 728
Share (%)	25	56	8	6	5	100

Source: own study based on the research carried out.

The second group were domestic tourists, for whom cruises were one of the many attractions of choosing Kołobrzeg as their place of stay. It was the largest group of 148,248 passengers, i.e. nearly 56% of all tourists using sea cruises. As far as the structure of the household is concerned, it was most often a family of three people. Tourists from the wider area dominated, but some also came from the region of the West Pomeranian Voivodeship. The possibility of taking advantage of tourist cruises was one of the reasons for them to choose Kołobrzeg as a place of rest. Therefore, and as in the case of foreign tourists, it was assumed that one day of stay in Kołobrzeg was related to tourist cruises. The average expenditure of one tourist amounted to PLN 287. The discussed group of tourists spent the most funds on accommodation PLN 109 (38%) and food PLN 89 (31%). On the other hand, much less for transport PLN 48 (17%) and the purchase of goods PLN 26 (9%) and other services PLN 15 (5%).

The third group consisted of domestic tourists from the wider environment, for whom cruises were the main reason for choosing Kołobrzeg as their place of stay. This was a group of 21,178 tourists (8%). The group in question was dominated by families of three. The main reason for choosing Kołobrzeg was the possibility of taking advantage of tourist cruises. They were usually weekend tourists, spending two days in Kołobrzeg. The average expenditure per tourist was PLN 518. The largest expenses were related to accommodation PLN 135 (26%), food PLN 141 (27%) and transport PLN 145 (28%). Much less funds were spent on the purchase of goods PLN 63 (12%) and other services PLN 34 (7%).

The fourth group consisted of domestic tourists from the closer environment, for whom cruises were the main reason for choosing Kołobrzeg as their place of stay. They were the smallest group of 15,884 tourists (6%). The structure was dominated by families of three, but also school trips. As in the previous group, the main motive for choosing Kołobrzeg was the possibility of using passenger transport. They were one-day tourists coming mainly from the West Pomeranian Voivodeship, who did not stay overnight. The average expenditure per tourist was PLN 171. In the discussed group, the largest expenses were related to transport PLN 78 (46%) and food PLN 60 (35%). Much less expenditure was consumed by the purchase of goods PLN 21 (12%) and other services PLN 12 (7%).

Residents of Kołobrzeg also participated in tourist cruises. But it was a small group, i.e. 13,236 tourists (5%). In their case, expenses made in the local economy cannot be linked to tourist cruises.

To sum up, in 2023, tourist expenditure could amount to PLN 82,213,329. The most important item was accommodation expenditure of PLN 29,628,440 (36%), followed by food expenditure of PLN 25,699,538 (31%) and transport expenditure of PLN 16,042,914 (20%). Expenditures on the purchase of goods of PLN 6,950,351 (8%) and on other services of PLN 3,892,086 (5%) were much less important. As far as individual groups are concerned, the largest amount of money was allocated for tourist cruises by domestic tourists, for whom cruises were one of many tourist attractions PLN 42,517,435 (52%), followed by foreign tourists PLN 26,004,065 (32%) and domestic tourists from further afield, for whom cruises were the main reason for choosing Kołobrzeg as their place of stay 10,970,204 (13%). On the other hand, domestic tourists from the closer environment spent the least, for whom cruises were the main reason for choosing Kołobrzeg as their place of stay, PLN 2,716,164 (3%).

On the other hand, the expenditure per one tourist amounted to PLN 311. The dominant position was occupied by expenditure on accommodation (PLN 112 (36%)), followed by food (PLN 97) (31%), transport (61%) (20%) and purchase of goods (26%) (8%). The lowest expenditures were related to other services 15 (5%).

Table 2.

Tourist expenditure (PLN) made in the local economy in 2023

Groups of tourists	Expenditure					Amount
	accommodation	board	transport	Purchase of goods	Other services	
Foreign tourists (cruises on one of the many tourist attractions)	161	129	70	22	11	393
	10 655 302	8 537 478	4 632 740	1 456 004	728 002	26 004 065
Domestic tourists (cruises on one of the many tourist attractions)	109	89	48	26	15	287
	16 114 108	13 222 922	7 100 412	3 826 569	2 253 424	42 517 435
Domestic tourists (cruises as the main attraction – closer surroundings)	0	60	78	21	12	171
	0	953 040	1 238 952	333 564	190 608	2 716 164
Domestic tourists (cruises as the main attraction – further surroundings)	135	141	145	63	34	518
	2 859 030	2 986 098	3 070 810	1 334 214	720 052	10 970 204
Amount	112	97	61	26	15	311
	29 628 440	25 699 538	16 042 914	6 950 351	3 892 086	82 213 329

Explanation:

- first line – expenses per person,
- Second row – Total expenditure.

Source: own study based on the research carried out.

The impact on the local and national economy is reflected in the expenditure multipliers. In the case of the local economy, expenditure on means of transport is of the greatest importance (Table 3). The value of the multiplier is 1.18, which means that one PLN spent on transport generates PLN 0.18 in the local economy. This is followed by expenditure on other services (multiplier value 1.17), purchase of goods (multiplier value 1.14) and accommodation and meals (multiplier value 1.12). On the other hand, the largest impact on the domestic economy was made by expenditure on accommodation and food (multiplier value of 1.80), followed by expenditure on transport (multiplier value of 1.76) and expenditure on other services (multiplier value of 1.68). The least important were expenditures on the purchase of goods with a multiplier value of 1.55.

Table 3.

Global output multipliers for local and national economies in 2023

Multiplier values	Expenditure			
	Accommodation and meals	Transport	Purchase of goods	Other services
Local economy	1,12	1,18	1,14	1,17
Domestic economy	1,80	1,76	1,55	1,68

Source: own study based on the research carried out.

5. Discussion

Previous research on the essence of the process of organizing and managing tourist expenses of cruise ship passengers shows a varied amount of expenditure per one tourist. In the Artal-Tur study (2018), it is EUR 25 for the port of Cartagena, which is much less than in the case of Kołobrzeg. The difference may be due to the nature of the port of Cartagena, which is the port of call. Passengers spend less during a few hours of sightseeing of the city (in the case of Cartagena) than, for example, tourists taking advantage of tourist cruises and spending two days in Kołobrzeg. It should be noted that in Kołobrzeg cruises take place without calling at ports. However, Cartagena is one of many ports of call, which limits the amount of expenses.

In turn, in a study by Vayá et al. (2017), tourists spend EUR 200, which is much more than in Kołobrzeg. It should be emphasized that the port of Barcelona is the home port. Which means that tourists bear the full costs, i.e. both transport costs and accommodation and food. The amount of expenditure may, however, be underestimated due to the significant share of local tourists (nearly 19%) who did not cover the full costs, including accommodation.

Research conducted by Tourists Barcelona shows that tourists spend an average of 156.4 euros in Barcelona during their holidays, which is not much less than in the study by Vayá et al. (2017). On the other hand, tourists for whom the port of call in Barcelona is the port of call spend an average of 53.3 euros. That is twice as much as in the Artal-Tur study (2018). The higher amount may be due to more tourist attractions in Barcelona.

In other surveys on ports of call, tourists spend €49.8 for the port of Cádiz (Coronado, 2008) and €62.6 for the port of Malaga (de Málaga, 2013).

On the other hand, in a study by Martin Associates (2014), tourists in the Seattle home port spend an average of \$180.

The above examples prove significant disparities in tourist expenses between home ports and calls. Tourists in Kołobrzeg spend less than in other home ports, although the disproportions are not so large. And if the study includes domestic tourists who spend two days in Kołobrzeg, the differences in expenses (PLN 518) are small. Pointing out unequivocally that the very process of organizing and managing tourist expenses of cruise ship passengers, the case study of the seaport in Kołobrzeg does not differ significantly from the above-mentioned averages for more attractive tourist destinations.

6. Summary and Conclusion

This article refers to the essence of the process of organizing and managing tourist expenses, cruise ship passengers, and a case study of the seaport in Kołobrzeg. On the basis of the research, five groups of tourists were distinguished, i.e.: foreign - for whom tourist cruises were one of many attractions, domestic - for whom cruises were one of many attractions, domestic - for whom tourist cruises were the main attraction, domestic from the wider environment - for whom tourist cruises were the main attraction, and locals.

Tourist expenditure in 2023 could amount to PLN 82,213,329. Tourists spent the most on accommodation, followed by food and transport, and the least on the purchase of goods and other services. Among the groups considered, domestic tourists were the most important for the local economy, for whom cruises were one of many attractions, which resulted from their numbers. On the other hand, foreign tourists spent on average 37% more than domestic tourists. At the same time, they spent more on accommodation, food and transport, and less on the purchase of goods and other services. On the other hand, per capita, the most important were domestic tourists from the wider environment, for whom tourist cruises were the main attraction, due to the length of their stay in the city. Individual tourists and families with children spent more than tourists traveling by collective transport. As far as the multiplier impact is concerned, transport expenditure was the most important for the local economy. In the case of the domestic economy, these were expenses for accommodation and meals as well as transport. The local economy is characterized by low self-sufficiency.

To sum up, it should be emphasized that tourist cruises carried out in Kołobrzeg have a long tradition. However, the growing trend has been halted first by the pandemic and now by the war in Ukraine. The market is becoming more and more competitive due to the involvement of small fishing vessels in tourist cruises. The increase in the attractiveness of tourist cruises

should be sought in their promotion, especially among foreign and domestic tourists, from the wider environment, for whom tourist cruises are the main attraction. Establishing network contacts with Polish and foreign ports should be considered. Therefore, we are facing a change not only in the organization and management of tourist expenses of cruise ship passengers, but also in the organization of the process of providing tourist services, which will certainly be a further area for research and analysis.

References

1. Artal-Tur, A., Navarro-Azorín, J.M., Ramos-Parreño, J.M. (2018). Estimating the impact of cruise tourism using regional input-output tables. *Anatolia*, 30(2), 1-11, <https://doi.org/10.1080/13032917.2018.1519209>.
2. Braun, B.M., Xander, J.A., White, K.R. (2002) The Impact of the Cruise Industry on the Region's Economy: A Case Study of Port Canaveral, Florida. *Economics of Tourism*, 8, 281-288.
3. BREA (2013). *Economic contribution of cruise tourism in Victoria 2012*. Retrieved from: <https://www.f-cca.com/downloads/2012-Cruise-Analysis-vol-1.pdf>, 3.11.2024.
4. Brida, J.G., Bukstein, D., Tealde, E. (2012). Patrones de gasto de cruceristas en dos puertos uruguayos [Pattern of Cruise Spending in Two Uruguayan Ports]. *Estudios y Perspectivas en Turismo*, 21, 5.
5. Central Statistical Office (GUS) (2019a). *Input-output tables*. Retrieved from: <https://stat.gov.pl/obszary-tematyczne/rachunki-narodowe/roczne-rachunki-narodowe/bilans-przeplywow-miedzygaleziowych-w-biezacych-cenach-bazowych-w-2015-roku,7,3.html>, 3.11.2024.
6. Central Statistical Office (GUS) (2019b). *Statistical Yearbook of Maritime Economy*. Retrieved from: <https://stat.gov.pl/obszary-tematyczne/roczniki-statystyczne/roczniki-statystyczne/rocznik-statystyczny-gospodarki-morskiej-2019,11,12.html>, 3.11.2024.
7. Central Statistical Office (GUS) (2023b). *Statistical Yearbook of Maritime Economy*. Retrieved from: <https://stat.gov.pl/obszary-tematyczne/roczniki-statystyczne/roczniki-statystyczne/rocznik-statystyczny-gospodarki-morskiej-2023,11,16.html>, 3.11.2024.
8. CERTeT Bocconi (2015). *Analisi dell'impatto socio-economico delle attività crocieristiche del porto di Civitavecchia*. Retrieved from: https://civitavecchia.portmobility.it/sites/default/files/file_uploads/impatto_socio_economico_crociere_civitavecchia_1432044905.pdf, 3.11.2024.
9. Chang, Y.-T., Liu, S., Park, H. (2016). The Economic Impact of the Cruise Industry Using Regional Input-Output Analysis: An Incheon Case Study. *Maritime Policy and Governance*, 43(1), 1-18, <https://doi.org/10.1080/03088839.2015.1086837>.

10. CLIA (2024). Retrieved from: https://cruising.org/-/media/clia-media/research/2024/2024-state-of-the-cruise-industry-report_updated-050824_web.ashx, 3.11.2024.
11. Connolly, K. (2020). Regional economic impact of offshore wind development in Scotland. *Renew Energy*, 160, 148-159, <https://doi.org/10.1016/j.renene.2020.06.065>.
12. Coronado, G.D. (ed.) (2008). *Evaluación del impacto económico del Puerto de la Bahía de Cádiz [Evaluation of the Economic Impact of the Port of Bahia de Cadiz]*. Cadiz: Universidad de Cádiz.
13. Coto-Millán, P., Mateo-Mantecón, I., Castro, J.V. (2010). Economic impact of ports: their importance to the region as well as to the hinterland. In: P. Coto-Millán, M. Angel, P.J. Castanedo (eds.), *Essays on the Economics of Ports* (pp. 167-200). Universidad De Cantabria, Springer. DOI:10.1007/978-3-7908-2425-4_13.
14. Danielis, R., Gregori, T. (2013). Input- and output-based methodology for estimating the economic role of a port: the case of the port system of the Friuli-Venezia Giulia region in Italy. *Maritime Economics & Logistics*, 15(2), 222-255, DOI: <https://doi.org/10.1057/mel.2013.1>.
15. De Málaga, P. (2013). *Análisis del Turismo de Cruceros 2012 [Prospects for Cruise Tourism in 2012]*. Málaga: Autoridad Portuaria de Málaga y Sociedad de Planificación y Desarrollo (SOPDE).
16. Dwyer, L., Forsyth, P. (1998). Economic importance of cruise tourism. *Annals of Tourism Research*, 25(2), 393-415.
17. Flegg, A.T., Tohmo, T. (2010). Regional Input-Output Tables and FLQ Formula: A Case Study of Finland. *Regional Studies*, 47, 1-48, <https://doi.org/10.1080/00343404.2011.592138>.
18. Flegg, A.T., Webber, C.D. (1997). On the proper use of location quotients in the generation of regional input-output tables: Answer. *Regional Studies*, 31, 795-805, <https://doi.org/10.1080/713693401>.
19. Flegg, A.T., Webber, C.D. (2000). Region size, regional specialization, and FLQ formula. *Regional Studies*, 34(6), 563-569, <https://doi.org/10.1080/00343400050085675>.
20. Jenniches, S. (2018). Assessment of the regional economic impact of renewable energy sources. Literature review. *Refurbish. Sustain. The Book of Energy*, 93, 35-51, <https://doi.org/10.1016/j.rser.2018.05.008>.
21. Kahouli, S., Martin, J.C. (2018). Can offshore wind energy be a lever for job creation in France? Some insights from a local case study. Env. Model evaluation. *Environmental Modelling and Assessment*, 23, 203-227, <http://dx.doi.org/10.1007/s10666-017-9580-4>.
22. Martin Associates (2014). *Economic impact of the Port of Seattle in 2013*. Retrieved from: http://www.portseattle.org/Supporting-Our-Community/Economic-Development/Documents/2014_economic_impact_report_martin.pdf, 03.11.2024.
23. Oleszczyk, N., Dominiak, N. (2021). Analysis of spa tourism on the example of Kołobrzeg. *Tourism/Tourism*, 31/1, 71-80, DOI: <https://doi.org/10.18778/0867-5856.31.1.08>.

24. Papadopoulou, G., Sambracos, E. (2014). Recent developments in cruise activities in European ports of embarkation: a quantitative and economic approach. *Archive of Economic History*, 1(26), 7-26.
25. Santos, A.M.P., Salvador, R., Quaresma Dias, J.C., Soares, C.G. (2018). Assessment of the economic impact of the port on the regional economy with a case study on the Port of Lisbon. *Maritime Policy and Governance*, 45(5), 684-698. DOI: <https://doi.org/10.1080/03088839.2018.1471536>.
26. Turisme de Barcelona (2015). *Encuesta de Cruceiristas 2014*.
27. Vayá, E., García, J.R., Murillo, J., Romaní, J., Surinach, J. (2017). Economic impact of cruises: Port of Barcelona. *Travel and Tourism Marketing Journal*, 35(3), 1-14, <https://doi.org/10.18778/0867-5856.22.1.04>.
28. Worley, T., Akehurst, G. (2013) *Economic Impact of the Cruise Sector in New Zealand*. Auckland: Market Economics Limited.

BEST PRACTISES IN ENVIRONMENTAL MANAGEMENT AMONG THE POLISH PUBLIC ADMINISTRATION BODIES PARTICIPATING IN THE EMAS SCHEME

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Purpose: The purpose of this paper is to present best practices in environmental management for offices, consistent with the sectoral reference document, implemented in the Polish public administration bodies participating in the EMAS scheme.

Design/methodology/approach: The assumed research method was based on the analysis of secondary sources in form of environmental statements. The selection of sample was targeted and the research involved a complete analysis among 19 organisations conducting business activity identified with the NACE code 84, for which sectoral reference document introduced by the Commission Decision (EU) 2019/61 of 19 December 2018 is applicable. Additionally, each organisation runs office activities. The described analysis allowed to identify most frequently used practices oriented on reducing environmental impact of office operations.

Findings: Most frequent practices identified among the research participants include printing on both sides, printing only necessary documents, electronic document flow, turning off redundant equipment and light, monitoring and reporting failures of water supply system, waste sorting and rational planning of commuting and business trips. Practices listed above can be implemented in organisations with different profile of activity, and also in households.

Research limitations/implications: The described research was limited to a certain extent, because some organisations had not indicated environmental management practices in their reports, or listed only part of the implemented actions. Further research might focus on practices used in public administration bodies, e.g. in the area of mobility or sustainable energy and climate policy.

Practical implications: The key input of the described research are examples of environmental management practices that could be implemented in organisations with different profile of activity and also in households.

Social implications: This study presents examples of activities important for the fulfilment of the EU sustainability goals, mainly focused on the improvement of overall quality of life.

Originality/value: The outcomes of the study can supplement previous research concerning the EMAS scheme with examples of specific solutions implemented in public administration bodies (and possible to implement in most organisations) in order to reduce the negative environmental impact.

Keywords: EMAS scheme, sustainability, sectoral reference documents, public administration.

Category of the paper: Research paper.

1. Introduction

Sustainability is a major goal of the recent EU policy. It basically refers to continuous improvement of the quality of life and well-being of the present and future generations, which is quite difficult to achieve considering the rapid climate changes and growing demand for energy and resources. In order to face the challenges in this area, the EU has taken a series of initiatives, including the Action Plan for sustainable consumption, production and industry of 16 July 2008 (COM(2008) 397 final). It underlines the significance of the shift to more sustainable consumption and production models, as well as the importance of a certain instrument (EMAS eco-management and audit scheme) that enterprises could apply in order to optimise their production processes. The EMAS scheme, mainly focused on supporting different organisations in the improvement of environmental performance (not only in the area of production processes), is said to be one of the most transparent environmental management systems (COM(2008) 397 final). In order to achieve satisfactory results, environmental initiatives must be taken in different sectors. The EMAS Regulation No. 1221/2009 of 25 November 2009 introduced a concept of sectoral reference documents, specifying best environmental practices that could be followed by organisations operating in different sectors in order to reduce their negative environmental impact. The key sectors for which those documents are needed have been determined considering, among others, higher participation in the EMAS scheme within a given sector, and the potential for improvement of environmental protection activity within the value chain of a given sector. Public administration has been listed among the sectors whose participation in environmental protection activities was particularly important (2011/C 358/02).

This study is an attempt to supplement the knowledge concerning particular actions implemented by organisations participating in the EMAS scheme (public administration sector in this case) in order to improve their environmental performance. Supplementing this knowledge is important in the context of fulfilment of the EU sustainability goals and presenting specific solutions that could be implemented in organisations from different sectors, to improve their performance in various areas (e.g. energy efficiency, water consumption, waste management and use of materials).

2. Best practices in environmental management to be implemented in the public administration sector

As it has already been mentioned, EMAS Regulation No. 1221/2009 obliged European Commission to draft sectoral reference documents for various branches of industry. Public administration is among the key sectors for environmental protection initiatives. Best practices in environmental management proposed for that sector include specific actions that could be implemented to improve office management systems, energy efficiency, mobility, resources management, air quality, land usage as well as water supply and sewage management. Additionally, environmental performance indicators, benchmarks of excellence and rating systems identifying environmental performance levels have been proposed. Organisations already participating or preparing to register in the EMAS scheme are obliged to follow valid reference documents in the development and implementation of their own environmental management systems, and also to evaluate their environmental performance (respective results are presented in an environmental statement). However, it needs to be mentioned that organisations are obliged to follow only those practices and indexes that are relevant for their business activity and identified significant environmental aspects (Commission Decision (EU) 2019/61..., 2018).

Environmental practices listed in the sectoral reference document for the public administration sector encompass several areas. They include best practices in environmental management related to environmentally-friendly office operations. They are addressed to all public administration bodies dealing with office work. In this area, organisations should focus on management and reduction of energy and water consumption, management and reduction of the volume of waste, reducing paper and office supplies consumption, minimising the environmental impact of commuting, business trips, canteen, cafés and reducing the environmental impact of meetings and events. As far as management and reduction of energy and water is concerned, regular collection or continuous monitoring of consumption data is recommended, as well as analysing data, setting goals, determining reference values to evaluate actual consumption, and also developing a strategy and action plan to improve energy characteristics of particular office buildings or reduce water consumption. Examples of specific solutions that could be implemented in this area by public administration bodies include: installing energy-efficient equipment, introducing proper energy management systems, energy efficiency training for key staff responsible for building and energy management, involvement of all employees in activities aimed at reducing energy consumption, e.g. turning off lights or proper adjustment of indoor temperature, installing and regular maintenance of water-efficient faucets and reduction valves, installing rainwater collection systems.

As far as management and reduction of waste is concerned, organisations should focus on the implementation of advanced office waste management patterns, based on preventing, sorting and monitoring waste production. Specific practices that could be adopted in this area include departing from paper-based procedures and archiving, ensuring sustainability and possibility to reuse office furniture and equipment, encouraging employees to use reusable dishes and easy access to separated waste collection bins.

In the field of reduction of paper and office supplies consumption, the best environmental management practice for public administration bodies is the implementation and promotion of proper internal procedures (e.g. electronic document flow, printing on both sides) and switching to green public procurement patterns, in order to stimulate making more environmentally-friendly choices.

The recommended solutions in the field of commuting and business trips include encouraging employees to follow more environmentally-friendly behaviour patterns, drafting business trip schedules, reducing the scale or effective management of commuting by car, allowing employees to work in a way that reduces the need to commute (e.g. remote work, videoconferencing).

As far as minimising the environmental impact of canteens, cafés, meetings and events, best practices include implementing sustainable canteen/café/event management system and following environmental criteria when choosing meals or meeting venue. In this area, EMAS system has also been referred to as a criterion for hotel or service provider selection (Commission Decision (EU) 2019/61..., 2018).

As it has already been mentioned, the purpose of a sectoral reference document is to provide support to organisations seeking improvement of their environmental performance, by indicating practical solutions and technical guidelines, possible to adopt within the organisation. Although that document is primarily addressed to organisations already participating in the EMAS scheme or intend to register in the scheme, it can serve as a source of inspiration or practical solutions for public administration bodies that do not participate in the EMAS scheme.

3. Review of previous research concerning the EMAS scheme

The previous research concerning the EMAS scheme mainly focused on determining the motivation, problems and benefits related to the process of implementation of the EMAS system. The most frequently cited benefits include environmental effects. These were mostly related with reorganisation and systematisation of previous activities in the environmental protection field (Freimann, Schwaderlapp, 1996; Hillary, 1998; Bohne, 2000; Steger, 2000; Umweltbundesamt, 2000; Kossler et al., 2002; Morrow, Rondinelli, 2002; Hyršlova, Hajek,

2005, 2006; Abeliotis, 2006; Ministerio De Medio Ambiente, 2006; Nycz-Wróbel, 2016); reducing the negative environmental impact, mainly as a result of the reduction in produced waste as well as smaller energy and resources consumption (Bültman, Wätzold, 2000; Schucht, 2000; Umweltbundesamt, 2000; Braun, Grotz, 2002; Wenk, 2004; Hyršlova, Hajek, 2006; Vernon et al., 2009; Nycz-Wróbel, 2016), and also improvement of environmental performance (Hillary, 1998; Morrow, Rondinelli, 2002; Hillary, 2004; Daddi et al., 2011; Merli et al., 2014; Nycz-Wróbel, 2016). Among specific solutions adopted as a result of the implementation of the EMAS scheme were technical improvements within the facilities and installations owned by the company, implementing new or optimising current technological processes, replacing problematic materials and improvement of product environmental efficiency. This type of solutions has been adopted in French and German enterprises (Bültmann, Wätzold 2000; Schucht, 2000). Certain studies present specific solutions adopted in Polish power engineering and manufacturing enterprises in order to reduce emission of airborne contaminants. These include the use of modern low-emission technologies or improvement of previous technologies, modernisation of facilities and installations, monitoring and measuring level of emissions, employing flue gas treatment systems, containment of processes and improvement of transport operations (Nycz-Wróbel, 2021; 2021a). Beside that, the review of the previous research concerning the EMAS scheme has shown particular activities adopted in Polish enterprises in order to improve energy efficiency. Among them were: replacement or modernisation of systems and devices, improvement of manufacturing processes, installing modern lighting systems, monitoring consumption of energy utilities (with the introduction of additional measurement indicators in this field), implementing an energy management system, energy audits and raising awareness of employees and customers (Nycz-Wróbel, 2020). As far as the public administration sector is concerned, the research conducted in the United Kingdom, Germany and Italy, as well as other studies in the EU countries and Poland, focused mainly on the EMAS scheme implementation and seeking solutions to facilitate maintenance and effective use of that system in public administration bodies (Jungwirth, 2011; Petrosillo et al., 2012; Matuszak-Flejszman, 2016; Hajduk-Stelmachowicz, 2018). Other available studies present the motivation, barriers and benefits of the EMAS scheme implementation, among others, in the public administration sector. However, they do not identify specific solutions adopted in order to improve the environmental performance of described organisations (Vernon et al., 2009). A research conducted among Italian public administration bodies concerned the reasons to withdraw from the system, as well as possible measures that could encourage participants to return to the EMAS scheme (Merli et al., 2017).

The review of the published studies has shown that the knowledge of specific practices and solutions adopted in the public administration bodies in order to improve their environmental performance, could be supplemented. This study is an attempt to supplement that knowledge, and described outcomes might be significant for the identification of solutions that could be adopted both in the public administration bodies, and in the private business sector.

4. Aim and method

The purpose of this paper is to present best practices in environmental management for offices, consistent with the sectoral reference document, implemented in the Polish public administration bodies participating in the EMAS scheme.

The theoretical part of the paper presents the concept of sectoral reference documents, as well as best environmental practices listed therein, that could be adopted in the public administration sector to reduce the environmental impact of office operations. Public administration sector has been described as one of the key sectors involved in the environmental protection activity. Additionally, the results of previous desk-research analysis regarding organisations participating in the EMAS system have been presented, in order to indicate information that needs to be supplemented, concerning particular solutions implemented by the analysed organisations in order to improve their environmental performance.

The empirical part contains the results of individual research conducted among the Polish public administration bodies participating in the EMAS scheme. The grounds for the assumed research method was the analysis of secondary sources in form of environmental statements. These are obligatory reports submitted by organisations participating in the EMAS scheme, that must be drawn up, published and updated on a regular basis. Additionally, public administration bodies are obliged to include sectoral reference documents (if possible) in their environmental statements when assessing the effects of their environmental activities, which allows us to find specific examples of environmental practices adopted in those organisations.

The analysis of environmental statements has already been used as the basic research tool, among others in the study on the effect of EMAS implementation on the improvement of environmental performance (Daddi et al., 2011; Matuszak-Flejszman, 2019; Heras-Saizarbitoria, 2020; Nycz-Wróbel, 2020).

The selection of sample was targeted and the research involved a complete analysis among 19 organisations conducting business activity identified with the NACE code 84, in which sectoral reference document introduced by the Commission Decision (EU) 2019/61 of 19 December 2018 is applicable. Additionally, each organisation runs office activities. It is worth mentioning that two of the analysed organisations reported in their environmental statements that they had adopted practices consistent with a sectoral reference document, but these practices were not actually specified.

Environmental statements were downloaded from the official Polish EMAS website, as per the register dated 08 April 2024. The study was conducted from 08 April 2024 to 30 April 2024. An in-depth analysis of environmental statements allowed to determine the best environmental management practices presented by individual organisations.

Next, these practices were arranged based on the sectoral reference document, and divided into 7 groups: management and reduction of energy consumption, management and reduction of water consumption, management and reduction of waste production, reducing paper and office supplies consumption, reducing environmental impact of commuting and business trips, reducing environmental impact of canteens and cafés and reducing environmental impact of meetings and business events. The results have been presented in tables.

5. Research outcomes

Table 1 presents a summary of best practices in environmental management for offices, consistent with the sectoral reference document, implemented in the Polish public administration bodies participating in the EMAS scheme.

Table 1.

Best environmental management practices in office operations adopted by the Polish public administration bodies

Practice	Number of organisations
Reducing paper and office supplies consumption	15
Management and reduction of energy consumption	13
Management and reduction of water consumption	13
Management and reduction of waste production	13
Reducing environmental impact of commuting and business trips	13
Reducing environmental impact of meetings and business events	3
Reducing environmental impact of canteens and cafés	0

Source: individual research based on the analysis of environmental statements.

Most of the analysed organisation from the Polish public administration sector adopted environmental practices oriented on reducing paper and office supplies consumption (15). Other frequently used practices also included activities in the field of reduction of energy and water consumption, waste production, as well as reduction of negative environmental impact of commuting and business trips. These practices were indicated in environmental statements of 13 analysed organisations. The least frequent activities reported by the analysed Polish public administration bodies were aimed at reducing environmental impact of business meetings and events (3). None of the analysed organisations reported activities leading to reduce the environmental impact of canteens and cafés.

Table 2 presents the activities related to reducing paper and office supplies consumption.

Table 2.

Best environmental management practices in reducing paper and office supplies consumption in Polish public administration bodies

Practice	Number of organisations
Printing on both sides	13
Reducing the amount of printouts, printing only if necessary	12
Electronic document flow	10
Reusing paper written on one side (e.g. as a draft or internal printed document)	8
If possible, disseminating information and documents to colleagues via e-mail	5
Common high efficiency printers and quick scanners (so-called “central printing system”)	5
Printing final version of documents upon manager's approval of electronic document contents	3
Planning optimum content and print layout (in order to reduce the number of printed pages)	3
Using environmentally-friendly certified recycled paper	3
Electronic drafting of letters and internal correspondence	1
Checking if document is finished before printing	1
Following the “Green Public Procurement” principle when planning purchase of products and services	1
Preparing single copy of proposed solutions (printing the legally required number of copies only after final approval of the manager)	1
Gradual shift from paper to digital documentation	1
Continuous monitoring of paper purchase and consumption	1
Taking only necessary amount of paper towels from the dispenser	1

Source: individual research based on the analysis of environmental statements.

The most frequent practices include printing on both sides (13), reducing the number of printouts (12) and implementing electronic document flow (10). As far as the first of the listed practices is concerned, some organisations reported that double-sided printing is used whenever possible, two organisations used default setting to print on both sides, while four other organisations claimed that it was an obligatory rule within the whole unit. When it comes to minimising the number of printouts, the analysed organisations checked if a given document had an electronic version (in that case, printing was not necessary). They also gave up printing reports, bulletins and meeting documents; while one of the research participants reported reduction of colour printouts, and another claimed that they used only grey scale printouts. The activities related to the implementation of electronic document flow included introduction of an electronic document management system, using the e-PUAP messaging system, placement of internal regulations, contracts agreements, comments to legislative acts, attorney documents, etc. on a common server, and also using electronic signatures. Most frequent practices to reduce paper and office supplies consumption include reuse of paper printed on one side (8), dissemination of documents and information to employees via e-mail whenever possible (5) and replacing individual printers with common high-efficiency devices and quick scanners, optimally placed within the organisation building (5). As for the latter practice, one of the analysed organisations reported that their HR and accounting departments were allowed to use individual printers due to the confidential character of processed documentation.

Table 3 presents specific activities in the energy management area.

Table 3.

Best environmental management practices in managing and reducing energy consumption in Polish public administration bodies

Practice	Number of organisations
Switching off redundant office equipment and air conditioning units, without leaving them in standby mode	10
Turning off light while leaving the room and in rooms that are not in use for a longer time	7
Avoiding to use artificial lighting in bright and sunlit rooms	5
Turning off light when living toilet or kitchen	5
Rational use of coffee machine or kettle	3
Reporting drafty windows and doors (to prevent heat loss)	2
Reducing heating while airing rooms / closing doors and windows in air-conditioned rooms	2
Installing automatic screen savers	2
Adjusting cooling and heating efficiency in office rooms	2
Automatic light switches in toilets	1
Replacement of lighting and electric/electronic equipment	1
Replacement of individual printers with large high-efficiency printers	1
Continuous monitoring of energy consumption (e.g. by comparing invoice amounts)	1

Source: individual research based on the analysis of environmental statements.

The largest group of the analysed organisations adopted the practice consisted in turning off redundant office equipment and air conditioning units (10). Other frequent practices include turning off lights in unoccupied rooms (7), toilets and kitchen (5), as well as the use of natural light in bright rooms (5).

Table 4 presents practices related to water consumption management.

Table 4.

Best environmental management practices to reduce water consumption in Polish public administration bodies

Practice	Number of organisations
Encouraging employees to reduce water consumption	8
Monitoring and reporting water supply system failures	4
Turning off toilet and kitchen faucets completely	3
Boiling as much water as needed	3
Efficient use of dishwasher	2
Checking if faucet is turned off completely	1
Continuous monitoring of water consumption (e.g. by comparing invoice amounts)	1

Source: individual research based on the analysis of environmental statements.

The largest number of analysed organisations reported activities consisted in encouraging employees to reduce water consumption (8). Two out of eight organisations adopting that practice, used special labelling in the toilet and kitchen to remind their employees to save water: “It's great that you save water!” and “Save water”. Another frequent activities in the field of reduction of water consumption include monitoring and reporting water supply system failures (4), tight closing of faucets (3) and boiling as much water as needed (3).

Table 5 presents good practices in the waste management area.

Table 5.

Best environmental management practices in managing and reducing waste production in Polish public administration bodies

Practice	Number of organisations
Collecting municipal waste in properly labelled separate bins	12
Waste removal by authorised third-party companies	7
Ensuring proper access to separated waste collection bins	5
Folding cartons and compressing plastic packaging materials before placement in a bin	4
Avoiding the use of disposable plastic packaging, bags and cups	4
Proper care and maintenance of equipment provided by the company	3
Including a clause concerning required disposal of waste produced as a result of a service in contracts with third party providers	3
Implementing an electronic document management system	2
Avoiding to place plastic, paper and glass waste in office bins	1
Placing clean food packaging in recyclable waste bins	1
Reusing office furniture and equipment	1
Quantity and quality check of produced waste in accordance with the waste act requirements	1
Systematic review of waste storage areas	1
Continuous monitoring of waste production (by analysing waste removal receipts)	1
Continuous monitoring of quantity of purchased materials (to compare consumption)	1
Using environmentally-friendly cleaning agents	1
Training of employees in waste sorting principles	1

Source: individual research based on the analysis of environmental statements.

Most analysed organisations indicated separation of waste in properly labelled bins (12). Practices reported in this area also include waste removal by authorised companies (7), ensuring proper access to waste collection bins for employees and customers (5) and compressing packaging materials before placement in a bin to save space (4). Other reported activities include extending the life-cycle of devices and equipment. These practices were reported by 3 organisations and consisted in using professional cleaning, repair and maintenance service (e.g. car upholstery cleaning, repair of electronic equipment, inspection and maintenance of air conditioning units). One organisation developed a special procedure to enable re-use of furniture and office equipment. It assumed keeping an on-line list of redundant or used equipment (devices, furniture, office supplies) offered for purchase at a lower price to individuals and employees.

Beside that, the analysed organisations adopted practices aimed at reducing negative impact of commuting and business trips (Table 6).

Table 6.

Best environmental management practices to minimise environmental impact of commuting and business trips in the Polish public administration bodies

Practice	Number of organisations
Rational planning of business trips and commuting	8
Replacement of old cars with new, more environmentally-friendly vehicles	6
Commuting by bus or train, motorcycle, bicycle and other environmentally-friendly means of transport	4
Providing a secure bicycle parking area near the company building	3
Using the "eco-driving" principles	2

Cont. table 6.

Videoconferencing	2
Using an available integrated transport system, buffer parking or Park&Ride facilities	1
Involvement of management and EMAS team in promoting environmentally-friendly commuting during company meetings	1
Continuous monitoring of fuel consumption and mileage to check improvement	1
Regular checks of technical efficiency of company cars	1

Source: individual research based on the analysis of environmental statements.

Most organisations adopted the practice of rational planning of business trips and commuting (8). In order to achieve that, business trips were combined, individual rides were limited, business trips were planned to handle several issues in a given area, weekly work plan was introduced to plan business trips in advance (e.g. by combining trips to handle several issues), departures were scheduled in certain hours to avoid traffic jams, public transport (including railway) and carpooling were used, if possible. Another practices adopted to reduce the negative impact of commuting and business trips (in six organisations) include switching to more environmentally-friendly vehicles (Euro-6, hybrid) and commuting by public transport (4). In order to encourage employees to commute by bicycle, safe bicycle parking spaces were provided at the organisation's car park (3).

Polish public administration bodies also performed activities aimed at reducing negative environmental impact of business meetings and events (Table 7).

Table 7.

Best environmental management practices to minimise environmental impact of official meetings and business events in the Polish public administration bodies

Practice	Number of organisations
Withdrawal from the use of disposable tableware	2
Reducing the amount of gifts and content of conference materials	2
Switching to electronic training materials	1
Printing on recycled paper	1
Videoconferencing	1
Ordering water in reusable bottles	1
Taking into account environmental criteria while choosing service providers and venue for a meeting, conference or training	1

Source: individual research based on the analysis of environmental statements.

Practices related to reducing environmental impact of business meetings and events were listed in only three environmental statements. These activities include withdrawal from the use of disposable tableware (2) and limiting the content of conference materials (only leaflets and badges) (2). Conference materials were also provided in a downloadable electronic form. Another practice that is worth mentioning, is considering environmental criteria while choosing the venue or organiser of an event (1). In this aspect, the selection of strategic places within the region has been emphasised (to ensure easy access by public transport), as well as the selection of service suppliers that do not use disposable tableware.

6. Discussion

Public administration has been listed by the European Commission among the key sectors for the implementation of practices leading to the reduction of the negative environmental impact. It is also one of the sectors for which sectoral reference documents have been issued. They serve as a basis for organisations to develop their own set of environmental practices, adopted to improve environmental performance. This study focused on Polish public administration bodies participating in the EMAS scheme and identified specific actions taken to increase sustainability of office operations. It can be concluded that the analysed organisations were mainly oriented on five out of seven practices proposed in the sectoral reference document. These were: reduction of paper and office supplies consumption, management and reduction of energy and water consumption, management and reduction of waste production, and reducing environmental impact of commuting and business trips. Certain activities were frequently adopted in each of the listed areas. These include: print-on-both-sides principle, printing only necessary documents, electronic document flow, reuse of paper printed on one side (paper and office supplies), turning off redundant office equipment, air conditioning units and light (energy), encouraging employees to save water, monitor and report any failures within the water supply system, closing water faucets (water), proper sorting and disposal of waste (waste), rational planning of commuting and business trips, and switching to a more environmentally-friendly car (commuting and business trips). Comparing the outcomes of this study with the previous research is not easy due to the fact that the previous study (on specific activities implemented in organisations in order to improve their environmental performance) referred to enterprises, while this analysis concerns public administration bodies. However, that comparison indicates certain differences in the type of activities most frequently adopted in both groups of analysed organisations, which is related to the character of their operations. In enterprises, these were often quite expensive activities, that involved implementation of new technology or environmental improvement of existing processes, facilities and installations. In the public administration sector, most frequently adopted practices include initiatives adopted at the employee level, quite easy to incorporate into regular duties. It is worth noting that those simple practices can, or even should inspire enterprises and be adopted as a supplementary solution, beside more expensive improvements (considering the fact that all employees of an organisation should contribute to reducing the negative environmental impact). Improvement of energy efficiency could serve as an example. As it has been found in the previous research, one of the most frequent solutions adopted in enterprises (beside the costly modernisation of processes, installations and facilities, or time-consuming implementation of energy management systems), was raising awareness among employees and customers. In this field companies could adopt environmental practices implemented in the public administration sector, e.g. turning off redundant equipment, turning off light in unoccupied areas, or rational temperature adjustment.

When analysing the practices described herein, it should be emphasised that these actions could be adopted not only in the public administration sector, and not only to reduce the environmental impact of office operations. The majority of the presented practices can be applied, as it has already been mentioned, in enterprises seeking inspiration and ideas for activities that could help them improve their environmental performance e.g. in the fields of energy and water consumption, and waste management, as well as in any organisation dealing with office work. Even if a given organisation is more focused on one or two environmental aspects (e.g. energy and waste), they can additionally implement environmental practices in other areas, e.g. related with more rational use of office supplies and paper, or in the employees' commuting area.

These practices can be very useful for all organisations participating in the EMAS scheme (not only in Poland), that are obliged to provide environmental reports, indicating progress in six areas specified in the EMAS Regulation: energy efficiency, effective use of materials, water, waste, biodiversity and emissions (practices described herein apply to five out of six listed areas).

In the context of environmental protection, scalability is crucial, that could be achieved by systemic action and initiative of different groups of organisations, not only enterprises or public administration bodies. Many practices presented herein could be adopted in households, that have a significant role in the context of environmental protection activities.

7. Conclusions

The purpose of this paper was to present best practices in environmental management for offices, consistent with the sectoral reference document, implemented in the Polish public administration bodies participating in the EMAS scheme. This study allowed to identify certain practices most frequently used among the analysed organisations, aimed at reducing consumption of paper and office materials, energy and water, waste production, as well as environmental impact of commuting and business trips. The key input of the described research are examples of specific activities that could inspire or be readily implemented in different public administration bodies, companies with different profile of activity and households. It is particularly important for the fulfilment of one of the major goals in the EU sustainability policy. This study supplements previous research conducted among the organisations participating in the EMAS scheme.

The described research does not provide sufficient information to fill the gap in the knowledge concerning environmental practices implemented in the public administration bodies. Further research might focus on other practices mentioned in the sectoral reference document, concerning e.g. mobility or policy for sustainable energy and climate.

References

1. Abeliotis, K. (2006). A review of EMAS in Greece: is it effective? *Journal of Cleaner Production*, 14(18), 1644-1647.
2. Bohne, E. (2000). Voluntary Environmental Management Systems and Regulatory Relief. In: C.F. Bonser (Eds.), *Security, Trade, and Environmental Policy* (pp. 207-217). Boston, MA: Springer.
3. Braun, B., Grotz, R. (2002). Environmental Management in Manufacturing Industry: A Comparison Between British and German Firms. In: L. Schätzl, J.R. Diez (Eds.), *Technological Change and Regional Development in Europe* (pp. 273-292). Heidelberg: Physica.
4. Bültmann, A., Wätzold, F. (2000). *The Implementation of the European EMAS Regulation in Germany*. Leipzig-Halle: UFZ. Retrieved from https://www.researchgate.net/publication/265196953_The_Implementation_of_the_European_EMAS_Regulation_in_Germany, 1.09.2021.
5. Commission Decision (EU) 2019/61 of 19 December 2018 on the sectoral reference document on best environmental management practices, sector environmental performance indicators and benchmarks of excellence for the public administration sector under Regulation (EC) No 1221/2009 on the voluntary participation by organisations in a Community eco-management and audit scheme (EMAS).
6. Communication from the Commission — Establishment of the working plan setting out an indicative list of sectors for the adoption of sectoral and cross-sectoral reference documents, under Regulation (EC) No 1221/2009 on the voluntary participation by organisations in a Community eco-management and audit scheme (EMAS) (2011/C 358/02).
7. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan. COM(2008) 397 final.
8. Daddi, T., Magistrelli, M., Frey, M., Iraldo, F. (2011). Do environmental management systems improve environmental performance? Empirical evidence from Italian companies. *Environment Development and Sustainability*, 13(5), 845-862.
9. Freimann, J., Schwaderlapp, R. (1996). Implementation of the EU's EMAS Regulation in German companies. *Corporate Social Responsibility and Environmental Management*, 3(3), 109-112.
10. Hajduk-Stelmachowicz, M. (2018). Zarządzanie energią w regionalnych dyrekcjach ochrony środowiska zarejestrowanych w systemie ekozarządzania i audytu EMAS – aspekty wybrane. *Studia i Materiały*, 2(28), cz. 1, 26-36.

11. Heras-Saizarbitoria, I., Boiral, O., García, M., Allur, E. (2020). Environmental best practice and performance benchmarks among EMAS- certified organizations: An empirical study. *Environmental Impact Assessment Review*, 80.
12. Hillary, R. (1998). *An Assessment of the Implementation Status of Council Regulation (No. 1836/93) Eco-management and Audit Scheme in the Member States (AIMS-EMAS), Final Report*. Retrieved from: <http://aei.pitt.edu/38669/1/A3501.pdf>, 1.09.2021.
13. Hillary, R. (2004). Environmental management systems and the smaller enterprise. *Journal of Cleaner Production*, 12(6), 561-569.
14. <https://www.gov.pl/web/gdos/emas>, 8.04.2024.
15. Hyrslová, J., Hájek, M. (2005). Environmental Management Accounting in the Framework of EMAS II in the Czech Republic. In: P.M. Rikhardsson, M. Bennett, J.J. Bouma, S. Schaltegger (Eds.), *Implementing Environmental Management Accounting: Status and Challenges. Eco-Efficiency in Industry and Science*, 18. Dordrecht: Springer.
16. Hyršlová, J., Hájek, M. (2006). Environmental Management Accounting in Czech Companies that have Implemented Environmental Management Systems. In: S. Schaltegger, M. Bennett, R. Burritt (Eds.), *Sustainability Accounting and Reporting*. Dordrecht: Springer.
17. Jungwirth, M. (2011). *Environmental Management Systems in Local Public Authorities: a Comparative Study of the Introduction and Implementation of EMAS in the United Kingdom and Germany*. Peter Lang.
18. Kössler, W., Promberger, K., Stichauner, B., Waidhofer, S. (2002). *Evaluierung der Umsetzung der EMAS I-VO in österreichischen Unternehmen*. Universität Innsbruck. Retrieved from: <https://www.verwaltungsmanagement.at/602/uploads/10650109920.pdf>, 1.09.2021.
19. Matuszak-Flejszman, A. (2016). Korzyści z wdrożenia EMAS w kontekście zarządzania procesowego. *Studia Oeconomica Posnaniensia*, vol. 4, no. 12, 20-45.
20. Matuszak-Flejszman, A., Szyszka, B., Jóhannsdóttir, L. (2019). Effectiveness of EMAS: A case study of Polish organisations registered under EMAS. *Environmental Impact Assessment Review*, 74, 86-94.
21. Merli, R., Lucchetti, M.C., Preziosi, M., Arcese, G. (2017). Motivations behind the EMAS stagnation and enabling measures to stimulate new registrations: characterization of Public Administrations and Private-owned organizations. “Ten Years Working Together For a Sustainable Future”. São Paulo, Brazil, May 24th-26th, 2017.
22. Merli, R., Preziosi, M., Massa, I. (2014). EMAS Regulation in Italian Clusters: Investigating the Involvement of Local Stakeholders. *Sustainability*, 6(7), 4537-4557.
23. Ministerio De Medio Ambiente (2006). *Opinion study on the revision of regulation (EC) # 761/2001 (EMAS)*.

24. Morrow, D., Rondinelli, D. (2002). Adopting Corporate Environmental Management Systems: Motivations and Results of ISO 14001 and EMAS Certification. *European Management Journal*, 20(2), 159-171.
25. Nycz-Wróbel, J. (2016). Znaczenie implementacji systemu Ekozarządzania i Audytu (EMAS) w kontekście wzmacniania konkurencyjności przedsiębiorstw. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu, Zarządzanie strategiczne w teorii i praktyce no. 444*, 381-390.
26. Nycz-Wróbel, J. (2020). Realizacja założeń polityki energetycznej w polskich przedsiębiorstwach zarejestrowanych w systemie EMAS. *Studia i Materiały*, 1, 47-58.
27. Nycz-Wróbel, J. (2021). Activities undertaken by Polish manufacturing companies to reduce air emissions. *Problems and Perspectives in Management*, 19(3), 309-320.
28. Nycz-Wróbel, J. (2021a). Solutions Used by Polish Power Engineering Companies Registered in EMAS In Order to Reduce Emission of Air Contaminants. In: K.S. Soliman (Eds.), *Innovation Management and Sustainable Economic Development in the Era of Global Pandemic*. IBIMA.
29. Petrosillo, I., De Marco, A., Botta, S., Comoglio, C. (2012). EMAS in local authorities: Suitable indicators in adopting environmental management systems. *Ecological Indicators*, Vol. 13, Iss. 1, 263-274.
30. Schucht, S. (2000). *The Implementation of the Environmental Management and Eco-Audit Scheme (EMAS) Regulation in France, Research Paper 2000-B-2*. CERNA.
31. Steger, U. (2000). Environmental management systems: empirical evidence and further perspectives. *European Management Journal*, 18(1), 23-37.
32. Umweltbundesamt (Hrsg.) (2000). *EMAS in Germany, Report on Experience 1995 to 1998*. Umweltbundesamt Germany. Retrieved from: <https://www.umweltbundesamt.de/en/publikationen/emas-in-germany-report-on-experience-1995-to-1998>, 1.09.2021.
33. Vernon, J., Peacoc, M., Belin, A., Ganzleben, C., Candell, M. (2009). *Study on the Costs and Benefits of EMAS to Registered Organisations*. Milieu Ltd., Risk and Policy Analysis Ltd. Retrieved from: https://ec.europa.eu/environment/emas/pdf/other/costs_and_benefits_of_emas.pdf, 1.09.2021.
34. Wenk, M.S. (2004). EU's Eco-Management and Audit Scheme. *Environmental Quality Management*, 14(1), 59-70.

THE IMPACT OF SELECTED PASSENGER CAR MODELS ON ENVIRONMENTAL ELEMENTS

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Purpose: Educating the public about the impact of transport on the environment and health, which can lead to more informed consumer decisions and behaviours, as well as encouraging the use of more environmentally friendly means of transport, such as carpooling, electric vehicles or rail transport.

Design/methodology/approach: The Copert program was used to calculate the pollutant emissions from three Opel car models, while a measuring system consisting of a Bushnell vehicle speed meter, a microphone and a data acquisition card was used to determine the noise emissions. The measurements were carried out on specially selected sections of roads of different categories, characterized by different noise propagation conditions and acoustic obstacles. Sound pressure was measured during the passage of a single vehicle with speed measurement.

Findings: The opinion that diesel cars have the most negative impact on the environment is firmly established in the public consciousness. However, the analyses carried out clearly indicate that this view is true only in the case of nitrogen oxide emissions. Although NO_x is one of the main greenhouse gases affecting global warming, its presence in the environment leads to the formation of photochemical smog, acid rain and tropospheric ozone, which is harmful to our health and vegetation. However, it should be noted that the remaining emissions and their level in both diesel and petrol engines are at a similar level, which is caused by the evolution of diesel engine technology, which currently meets strict emission standards (Euro 6 and higher), thanks to which they emit less NO_x and PM than older models.

Social implications: The obtained results may increase public awareness of the negative impact of road transport on the environment and the need to change attitudes/habits in order to improve the quality of life.

Originality/value: This article presents the impact of three Opel passenger car models on selected environmental elements, taking into account noise emissions, as well as emissions of pollutants such as NO_x, SO_x, CO, CO₂, as well as emissions of suspended particulate matter PM_{2.5} and PM₁₀.

Keywords: environmental pollution, transport, noise, gaseous pollution, Copert program.

Category of the paper: research paper.

1. Introduction

There are currently around 1.5 billion passenger cars in the world, and over 250 million cars on European Union roads alone (OICA, 2024). At the end of 2022, there were around 26.7 million passenger cars registered in Poland, but after taking into account the so-called vehicles that are no longer in use but were still in the register, the real number was around 19.7 million. The number of passenger cars per 1000 inhabitants in Poland is 517, which puts the country in the European average, even though theoretically there are 700 vehicles per 1000 people, including older, unused cars. The average age of vehicles in Poland is around 14.9 years (GUS, 2024), which is a relatively high result, especially compared to other European Union countries, e.g. in Germany it is around 9.6 years, and in France 9 years, which places these countries among the countries with the younger car fleet in Europe (OICA, 2024). The number of cars in the world is expected to reach 2 billion by 2040 if the current growth rate is maintained. The increase in the number of cars is mainly driven by population growth, urbanization and increased access to vehicles in developing countries such as India and China.

The European Union is taking a number of actions to minimize the impact of transport on the environment, using various political, regulatory and technological tools. As part of its policy, the EU focuses on sustainable development, promoting more ecological forms of transport, as well as introducing strict standards and regulations on emissions. All of these actions require cooperation between governments, businesses, non-governmental organizations and society. Their success depends on a comprehensive approach and consistency in the implementation of the adopted strategies (Motowidlak, 2016).

Such a huge number of vehicles generates significant amounts of greenhouse gas emissions and air pollutants, such as NO_x, PM_{2.5}, CO₂ and CO and noise (Wisniewski, 2020; Souza de Abreu, 2022; Lin, 2021). The main causes of road noise include: high traffic density, vehicle speed, the share of heavy goods vehicles in traffic, poor technical condition of the road surface and vehicles, inefficient urban planning and the lack of provisions in noise regulations (Perzynski, 2019).

These vehicles also affect the degradation of ecosystems and the depletion of natural resources (Ferreira, 2018).

The current level of pollution and environmental exploitation by passenger cars emphasizes the need to develop low-emission technologies (e.g. EV, hydrogen), implement sustainable practices (car sharing, public transport), as well as introduce stricter emission regulations and promote recycling. It should be noted that the level of recycling of decommissioned motor vehicles in Poland is almost 100% (Ochocka, 2020), a perfect example of which is the recycling of used lead-acid batteries, which are most often used in this type of vehicles. EU Directive 2006/66/EC requires that lead-acid batteries be recycled at a rate of 65% (Directive, 2006), and in Poland the achieved level of recycling lead-acid batteries is above 95% (Baterpol).

In the presented work, research was conducted on the impact of selected brands of passenger cars on the emission of gaseous pollutants and noise levels.

2. Methodology

Three Opel car models were used in the study, i.e. Astra V with a petrol engine, Astra V with a diesel engine and Mokka with a petrol engine. The above-mentioned cars were manufactured in 2020, their mileage was 53,600 km, 55,000 km and 54,000 km, respectively. It should be noted that all the cars analyzed meet the strict Euro 6d standards. The technical parameters of the above-mentioned vehicles are presented in Table 1-3.

Table 1.

Technical data Opel Astra V, petrol engine, year of production 2020 (Automobile Catalog)

Engine	petrol 1.6 Turbo 200KM
Capacity (cm3)	1598
Gearbox	6-speed manual
Max power (HP at rpm)	200/4700-5500
Torque (Nm at rpm)	300/1700-4700
Current weight (kg)	1350
fuel consumption (extra-urban/urban/combined) (l/100 km)	5,0/8,0/6,1
CO ₂ emissions (g/km)	141

Table 2.

Technical data Opel Mokka, petrol engine, year of production 2020 (Automobile Catalog)

Engine	Benzynowy 1.4 Turbo 140 KM
Capacity (cm3)	1364
Gearbox	6-speed manual
Max power (HP at rpm)	103 przy 4900-6000
Torque (Nm at rpm)	200 przy 1850-4900
Current weight (kg)	1295 kg
fuel consumption (extra-urban/urban/combined) (l/100 km)	5,0/7,4/5,9
CO ₂ emissions (g/km)	139 (158)

Table 3.

Technical data Opel Astra V, diesel engine, year of production 2020 (Automobile Catalog)

Engine	Diesel 1.6 CDTI 136KM
Capacity (cm3)	1598
Gearbox	6-speed manual
Max power (HP at rpm)	136/3500-4000
Torque (Nm at rpm)	320/2000-2250
Current weight (kg)	1350
fuel consumption (extra-urban/urban/combined) (l/100 km)	3,6/5,2/4,2
CO ₂ emissions (g/km)	111

The first stage of the research was to measure the external noise generated by selected motor vehicles such as Opel Astra V and Opel Mokka. The measurements were carried out on specially selected sections of roads of different categories, characterized by different noise propagation conditions and acoustic obstacles. During the measurements, sound pressure measurements were carried out during the passage of a single vehicle with speed measurement, and the microphone was placed in all analyzed cases at a height of 1.5 m. The view of the measurement system is shown in Figure 1.

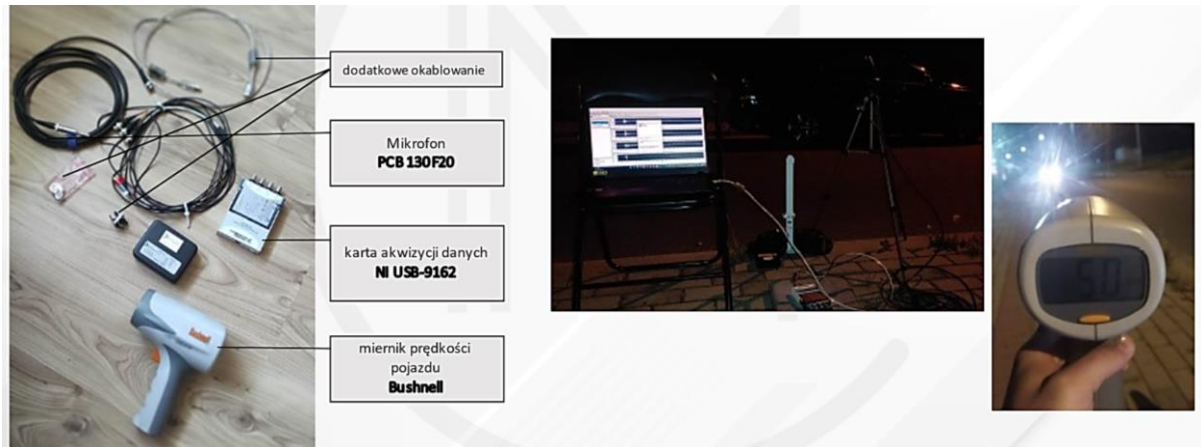


Figure 1. The measurement system used for research.

The research was carried out at four measurement points, i.e.:

- housing estate road - Mysłowice, Wybickiego Street,
- expressway - Sosnowiec S1,
- two-lane rural road - Mysłowice, Obrzezna Street,
- single-lane rural road - Jaworzno, Promienna Street.

The next stage of the research was modelling and estimating the emissions of selected chemical compounds emitted by the analysed vehicles using the Copert programme. Emissions in the programme are divided into 3 types: hot emissions - emitted from vehicles in motion, cold emissions - during engine start-up and evaporation during vehicle operation. Emissions of each group depend on the vehicle class, engine capacity and fuel type. It was necessary to determine the meteorological conditions (air temperature and humidity) for calculating air pollution emissions in the COPERT programme, as they affect air pollution, its intensity and duration. These data were downloaded from the archival sources of the website olframalpha.pl (table 4).

Table 4.*Monthly temperature and humidity in Katowice in 2023 (olframalpha)*

Month	min Temperature [°C]	max Temperature [°C]	Humidity [%]
January	-5,0	15,0	88,0%
February	-14,0	10,0	83,0%
March	-8,0	19,0	73,0%
April	-8,0	22,0	76,0%
May	-3,0	24,0	67,0%
June	2,0	30,0	68,0%
July	7,0	33,0	69,0%
August	6,0	31,0	77,0%
September	5,0	29,0	77,0%
October	-3,0	25,0	83,0%
November	-6,0	17,0	86,0%
December	-9,0	10,0	87,0%

3. Results and discussion

Example results of external noise measurements generated by selected motor vehicles are presented in Figures 2-5.

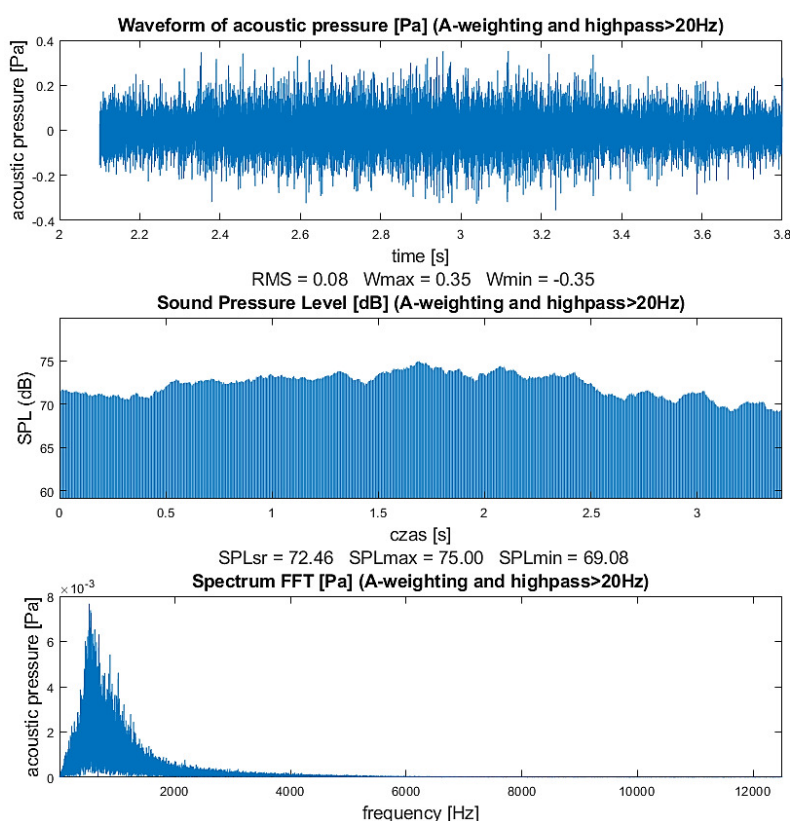


Figure 2. Opel Astra V, petrol engine, expressway, speed 85 km/h.

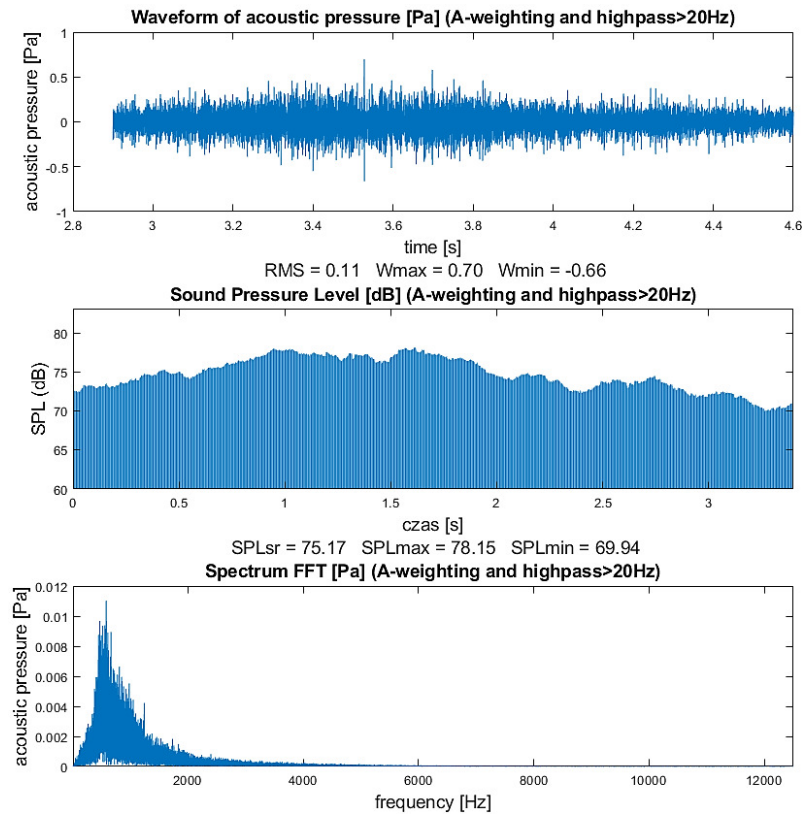


Figure 3. Opel Mokka: petrol engine, expressway, speed 85 km/h.

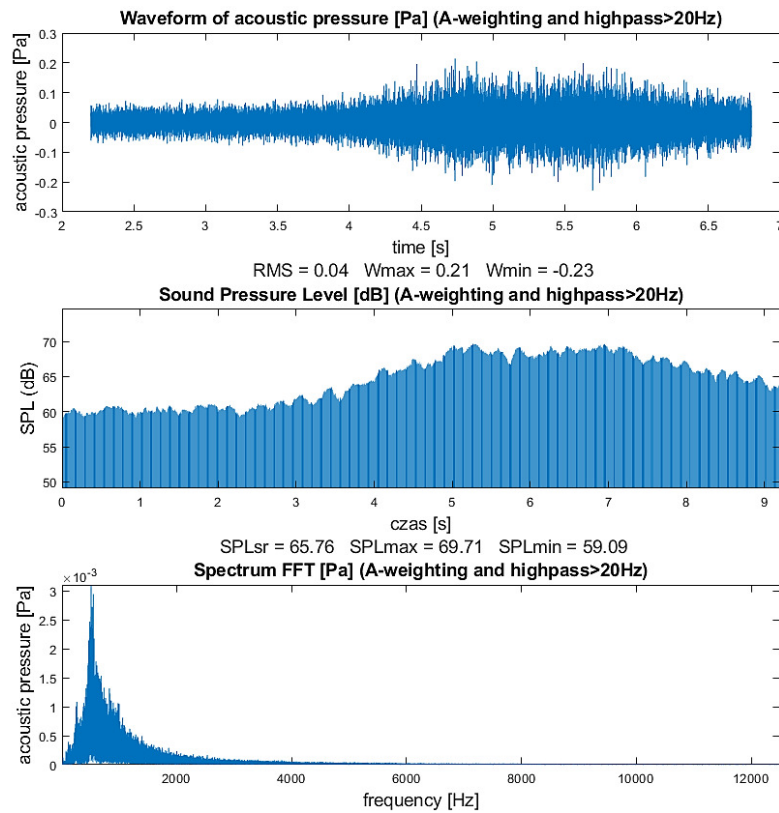


Figure 4. Opel Astra V, petrol drive, extra-urban road, speed 57 km/h.

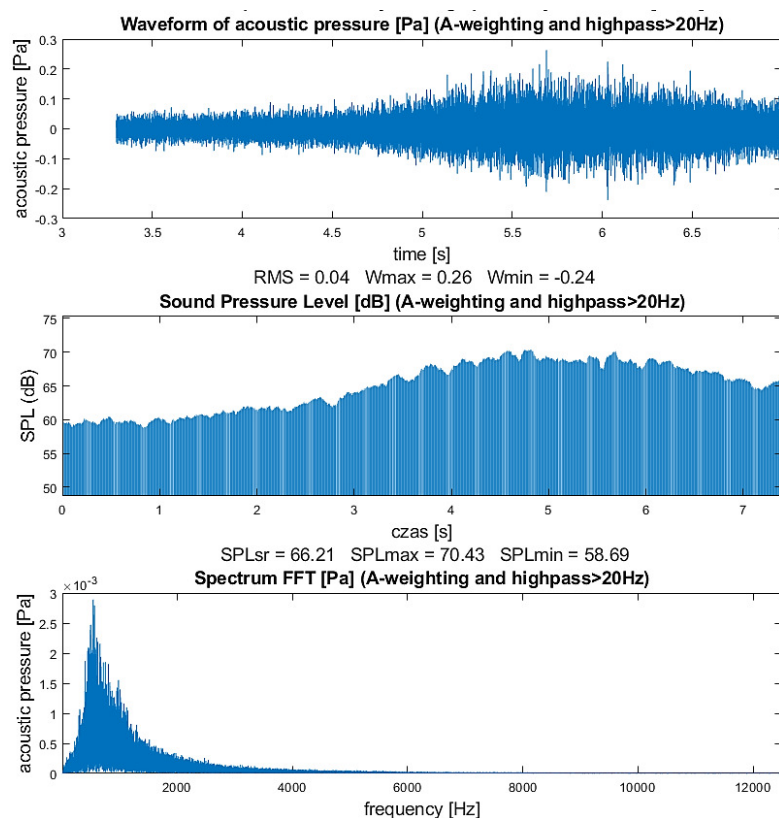


Figure 5. Opel Mokka, petrol engine, extra-urban road, speed 62 km/h.

In turn, example average values of sound levels on single- and two-lane expressways and suburban roads for the analyzed vehicles are presented in Figures 6-8.

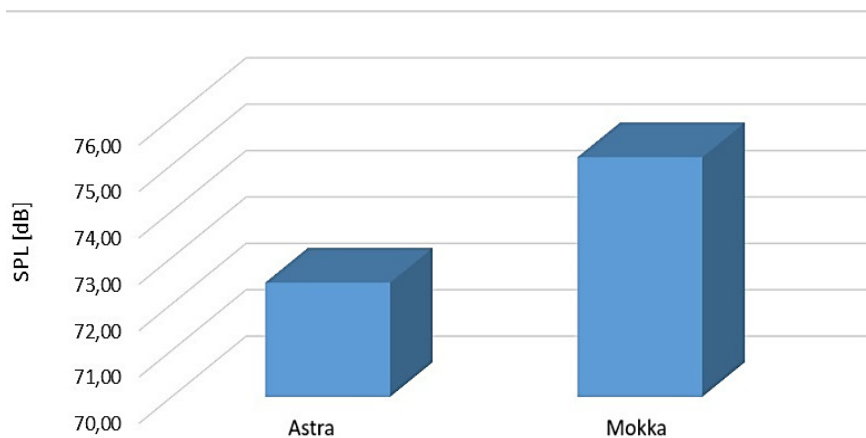


Figure 6. Average sound level values on an expressway for a petrol-powered Opel Astra V and Mokka vehicle at a speed of 85 km/h.

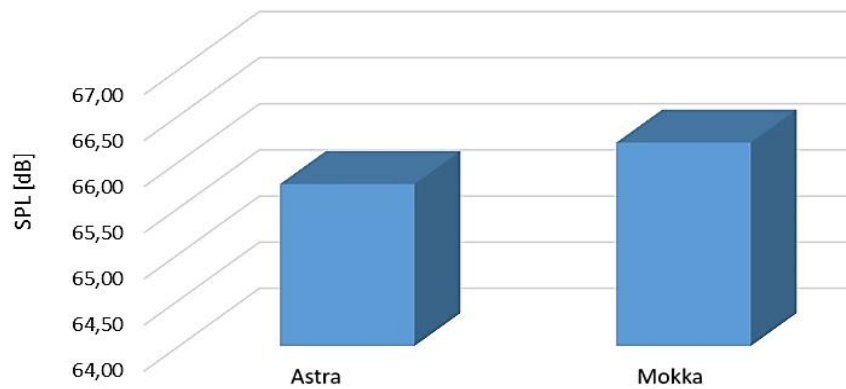


Figure 7. Average sound level values on a 2-lane suburban road for a petrol-powered Opel Astra and Mokka, at a speed of 60 km/h.

As shown in Figures 7 and 8, the average sound level on a suburban road generated by the petrol version of the Opel Mokka is higher than that of the Opel Astra V in the same fuel version for several reasons. The Opel Mokka is an SUV, with a higher silhouette than the Opel Astra V, which is a compact hatchback. The tall silhouette of the Opel Mokka (with a higher centre of gravity) can cause the generated air and wind noise, at higher speeds, to be more audible than in the lower Astra V. The Mokka, as an SUV, generates more air and mechanical noise, while the more compact Astra V, with better aerodynamics, is more effective in noise suppression.

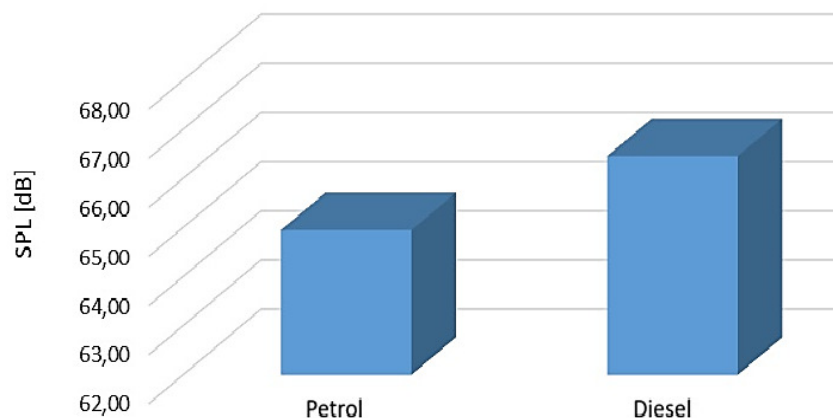


Figure 8. Average sound level values on a single-lane suburban road, for an Opel Astra petrol and diesel vehicle, at a speed of 60 km/h.

As Figure 8 shows, the average noise level of a car on a suburban road depends on many factors, and the higher noise level of diesel engines compared to petrol engines, as in the case of the Opel Astra V, may be due to several reasons. One is that diesel engines are noisier than petrol engines because they operate at a higher compression ratio. This creates higher cylinder pressures, which translates into higher engine noise. Additionally, diesel engines often have a rougher operating characteristic (more "knocker"), which can result in higher noise levels compared to petrol engines, which have a smoother operation. Diesel engines tend to operate at a lower RPM than petrol engines, but they generate more noise at the same speeds, due to the nature of the combustion and the difference in ignition technology.

When accelerating on a suburban road, where the engine load can vary, diesel engines often produce higher noise levels. Compared to petrol engines, diesel engines generate greater vibrations, which can contribute to increased noise inside the vehicle and can also affect the noise level outside the vehicle. The next stage of the study was to calculate the emissions of selected chemical compounds, i.e. CO, CO₂, NO_x, and PM_{2.5} dust for the Opel Astra with petrol and diesel engines, and the Opel Mokka with petrol engines, as shown in Figures 9-12.

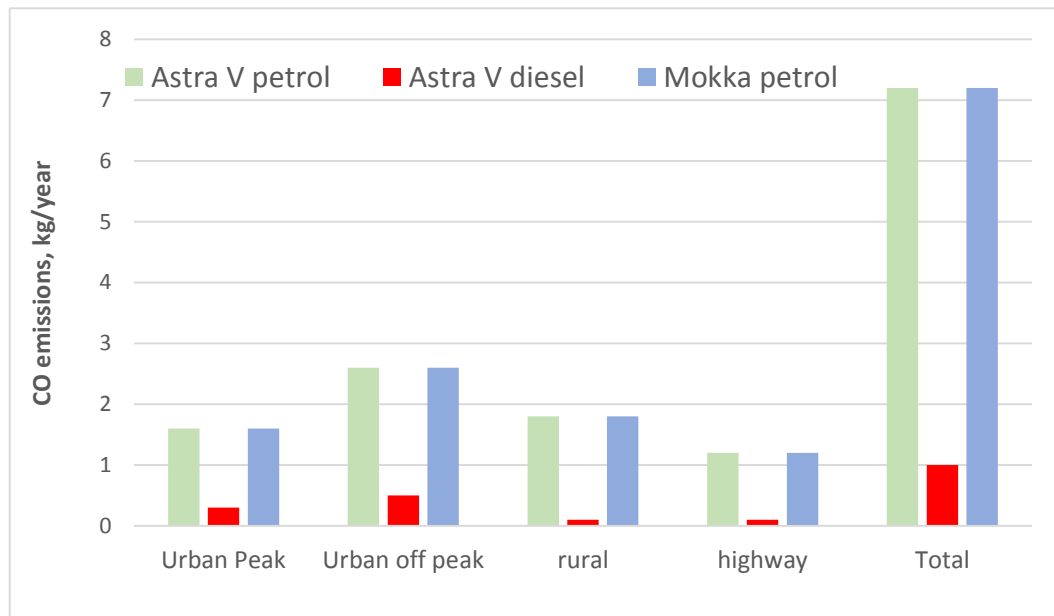


Figure 9. Emission of carbon monoxide (II) into the atmosphere in 2023 from the analyzed motor vehicles.

As shown in Figure 9, the Opel Astra with a diesel engine emits significantly less CO than the Opel Astra V and Opel Mokka with a petrol engine. It should be noted that diesel engines operate with an excess of air in the cylinder (a lean mixture), which means that they have more oxygen available to burn the fuel. This excess oxygen promotes complete combustion of the fuel, which reduces the formation of CO. Additionally, in petrol engines, where a mixture closer to stoichiometric (ideal air to fuel ratio) is used, a lack of sufficient oxygen at certain times can lead to incomplete combustion and increased CO emissions. In diesel engines, ignition occurs spontaneously as a result of compression, which causes the fuel to burn slowly and evenly, reducing the formation of carbon monoxide. In petrol engines, on the other hand, ignition is initiated by spark plugs, which leads to faster combustion. At higher loads or a lack of oxygen, incomplete combustion and increased CO emissions can occur. Diesel fuel used in diesel engines contains more hydrocarbons, but it burns better due to the specific combustion process in this type of engine, while petrol, due to its volatility and combustion characteristics, is more susceptible to incomplete combustion, which increases CO emissions.

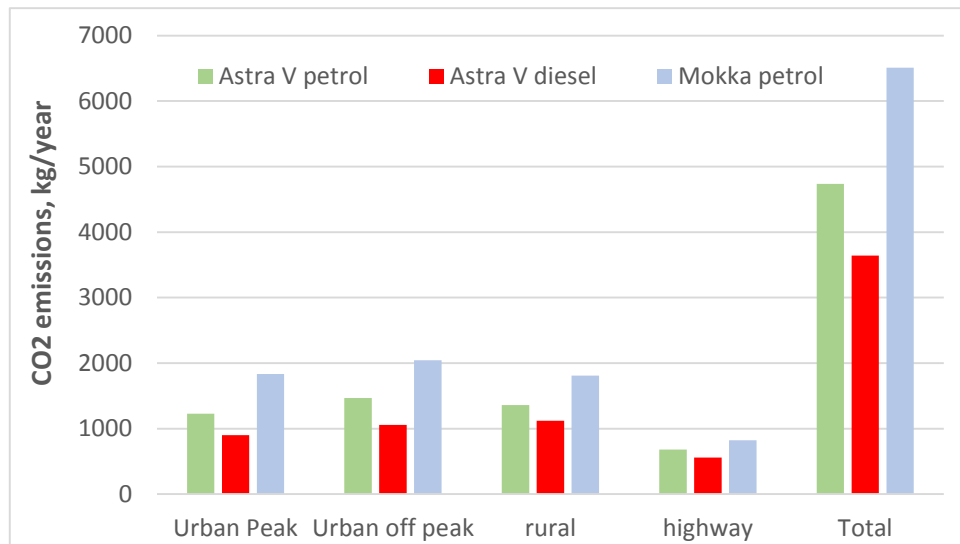


Figure 10. Emission of carbon monoxide (IV) into the atmosphere in 2023 from the analyzed motor vehicles.

As shown in Figure 10, petrol engines are characterized by higher CO₂ emissions than diesel engines, which results from differences in their design, combustion processes and fuel characteristics. Petrol engines have lower thermodynamic efficiency than diesel engines. This means that during the combustion process, a larger part of the energy from the fuel is converted into heat rather than into motion, which results in higher fuel consumption per unit of work. Higher fuel consumption leads to higher CO₂ emissions, because CO₂ is the main product of hydrocarbon combustion. In petrol engines, the combustion process takes place in a stoichiometric mixture, which is close to the ideal air-fuel ratio. In practice, this leads to more even combustion, but at the same time higher fuel consumption compared to diesel engines, which operate with excess air. Petrol engines usually operate at higher RPMs, which increases fuel consumption and CO₂ emissions, especially during dynamic driving. Diesels have a higher compression ratio (20:1 compared to 10:1 in petrol), which allows for more efficient use of the energy contained in the fuel. As a result, diesels use less fuel to travel the same distance, generating less CO₂. Additionally, petrol has a lower energy density, i.e. less energy per litre of fuel, than the diesel fuel used in diesel engines, so to generate the same amount of energy, a petrol engine must burn more fuel, which generates more CO₂.

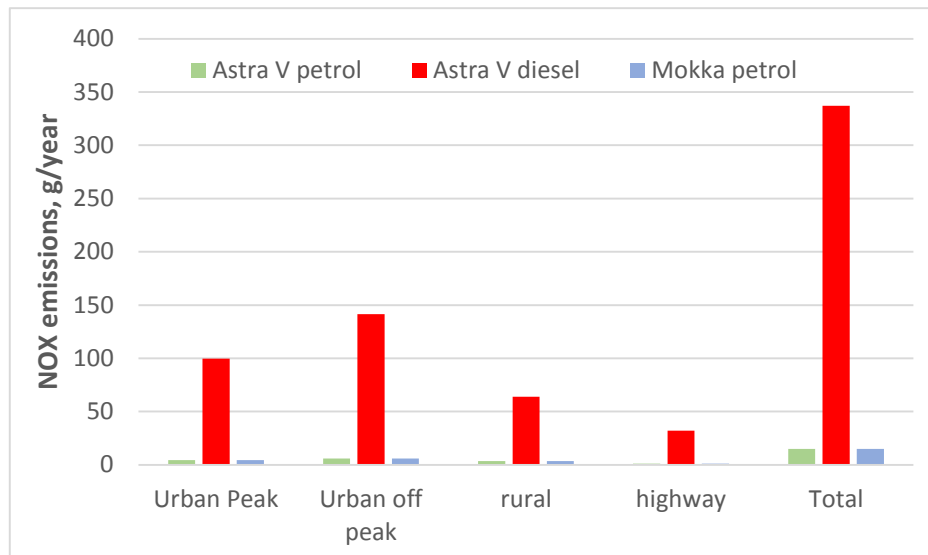


Figure 11. Emission of nitrogen oxide into the atmosphere in 2023 from the analyzed motor vehicles.

As shown in Fig. 11, nitrogen oxides (NO_x) emissions are higher in diesel engines than in petrol engines due to differences in their operating principles and combustion conditions. Diesel engines operate at a much higher compression ratio than petrol engines, which leads to higher combustion temperatures, and the high temperature promotes the formation of nitrogen oxides (NO_x), because nitrogen and oxygen from the air combine more intensively in such conditions. Diesel engines burn fuel in a lean mixture, with excess air. Such a mixture increases the combustion temperature, which also increases NO_x emissions. In diesel engines, ignition occurs through compression (compression ignition), which causes faster and more violent combustion than in petrol engines. This characteristic increases the combustion temperature and NO_x emissions.

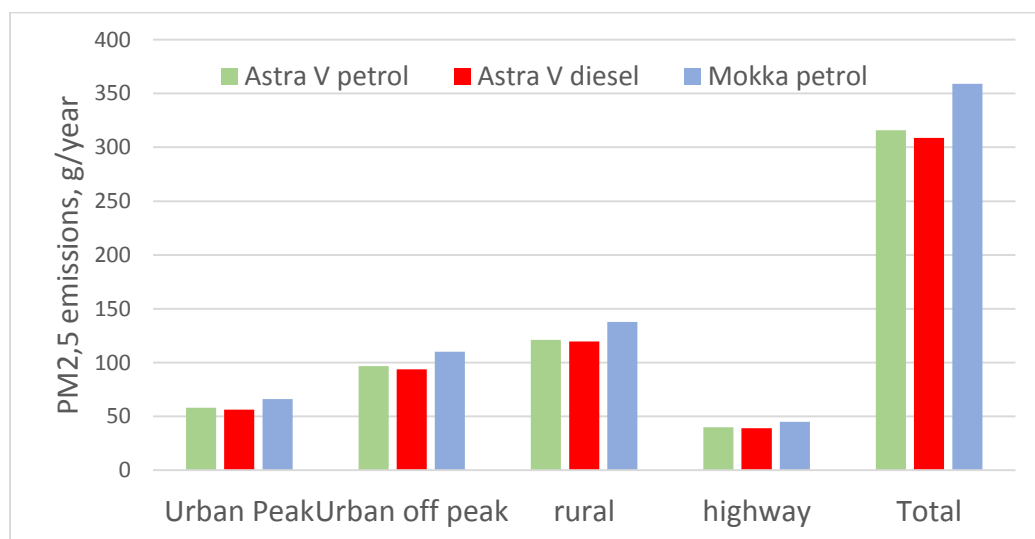


Figure 12. Emission of PM_{2,5} into the atmosphere in 2023 from the analyzed motor vehicles.

As shown in Fig. 12, the highest PM_{2.5} emission among the analyzed vehicles is from the Opel Mokka, regardless of the type of road traveled. This may be due to differences in construction, vehicle weight, materials used, and types of use. The Opel Mokka is a crossover,

and the Astra V is a hatchback. In the case of crossovers such as the Mokka, tires with a wider tread are often used, which generate more dust during abrasion compared to tires used in hatchbacks.

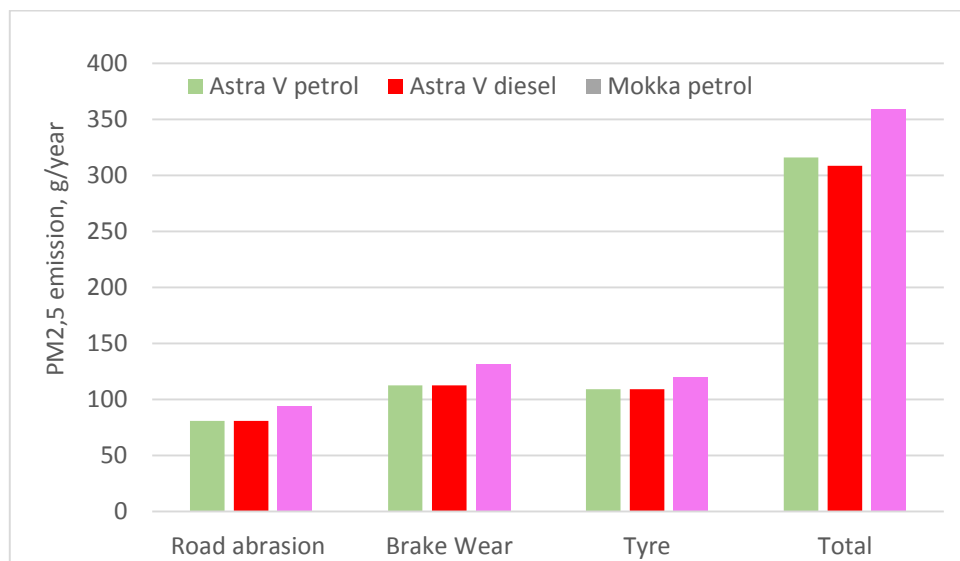


Figure 13. Sources and emissions of PM_{2.5} dust into the atmosphere from the analyzed motor vehicles.

As shown in Figure 13, PM_{2.5} dust emissions from the analyzed cars due to brake abrasion are significant, because the mechanical braking process uses the friction force between the brake pads and discs. As a result of this friction, fine particles are released, which are the main source of PM_{2.5} dust emissions. It should be noted that brake pads are made of a mixture of metals, resins, ceramic materials, and these materials are susceptible to disintegration under the influence of friction, and the products of this disintegration may contain fine PM_{2.5} particles. In addition, friction generates heat, which can cause degradation of the material of the pads and discs, releasing microscopic particles in the form of PM_{2.5} dust. Dust emissions from brakes go directly into the atmosphere at road level, which increases their impact on the environment and human health. In cities, where traffic is intense and requires frequent stopping, emissions related to braking are higher.

4. Conclusions

The analysis of the average sound level values shows that in all the analysed cases for the Opel Astra V with a diesel and petrol engine, higher values were recorded for the diesel-powered vehicle. The analysis of the sound level for the Opel Mokka with a petrol engine showed sound values similar to the levels recorded for the Opel Astra V with a diesel engine, despite the smaller engine capacity and lower total vehicle weight. This can be explained by the less aerodynamic shape of the Opel Mokka compared to the Opel Astra V.

In turn, the analysis carried out in the Copert program showed that CO₂ emissions of Opel Astra V and Mokka cars with petrol engines are higher than in the case of diesel engines, which results from differences in their design, differences in combustion processes and differences in fuel characteristics. Petrol engines have lower thermodynamic efficiency than diesel engines, which means that during the combustion process, a larger part of the energy from the fuel is converted into heat, not into movement, which results in higher fuel consumption.

In the case of CO emissions, Opel Astra with diesel engines emit significantly less CO than Opel Astra V and Opel Mokka with petrol engines. It should be noted that diesel engines operate with excess air in the cylinder (lean mixture), which means that they have more oxygen available to burn the fuel. This excess oxygen promotes full fuel combustion, which limits the formation of this type of pollution.

A different situation is observed in the case of NO_x emissions. Nitrogen oxides (NO_x) emissions are higher in diesel engines than in petrol engines due to differences in their operating principles and combustion conditions. Diesel engines operate at a much higher compression ratio than petrol engines, which leads to higher combustion temperatures, and the high temperature promotes the formation of nitrogen oxides (NO_x). In the case of PM_{2.5} emissions, the highest emission among the analysed vehicles was shown by the Opel Mokka, regardless of the type of road travelled. This may be due to differences in the design of the analysed cars, the materials used, and the way they are used. The Copert programme also showed that the highest NO_x emissions come from brake abrasion, because the mechanical braking process uses the friction force between the brake pads and the discs. As a result of this friction, fine particles are released, which are the main source of PM_{2.5} emissions.

The view that diesel cars have a more negative impact on the environment than petrol cars is deeply rooted in public awareness. However, the analyses carried out clearly indicate that this view is true only in the case of nitrogen oxide emissions. It should be noted, however, that the remaining emissions and their levels in both diesel and petrol engines are at a comparable level, which is due to the evolution of diesel engine technology, which currently meets strict emission standards such as Euro 6 and higher.

It should be emphasized that the conducted analysis of pollutant emissions from motor vehicles concerned three car models, i.e. Opel Astra V with diesel and petrol engines and Opel Mokka with petrol engine. A broader analysis will require performing similar studies for a larger number of car brands and models.

The social pressure caused by the results of pollutant emission analyses motivates companies to invest in more ecological technologies, e.g. low-emission engines or electric drive. Transparency of emission data makes manufacturers more responsible to consumers and legal regulations.

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References

1. Automobile Catalog, https://www.automobile-catalog.com/car/2020/2916590/opel_astra_1_2_direct_injection_turbo_145.html#google_vignette, 2.09.2023.
2. Baterpol (2024). <http://www.baterpol.pl>.
3. Directive 2006/66/EC on batteries and accumulators and waste batteries and accumulators, Directive of the European Parliament and of the Council (2006).
4. Ferreira, C.S.S., Walsh, R.P.D. Ferreira, A.J.D. (2018). Degradation in urban areas. *Current Opinion in Environmental Science & Health*, Vol. 5, pp. 19-25.
5. Główny Urząd statystyczny (2024), <http://www.gus.pl>.
6. International Organization of Motor Vehicle Manufacturers (2024). <https://www.oica.net>.
7. Lin, B.B., Ossola, A., Alberti, M., Andersson, E., Bai, X., Dobbs, C., Elmqvist, T., Evans, L.K., Frantzeskaki, N., Fuller, A.R. et al., (2021). Integrating solutions to adapt cities for climate change. *Lancet Planet. Health*, No. 5, e479-e486 [Google Scholar].
8. Motowidlak, U. (2016). *Znaczenie wykorzystywania paliw alternatywnych w transporcie samochodowym dla rozwoju gospodarki niskoemisyjnej Unii Europejskiej [The importance of using alternative fuels in road transport for the development of a low-emission economy in the European Union]*. University of Lodz Publishing House.
9. Ochocka, A. (2020). Analiza i diagnoza systemu recyklingu pojazdów wyłączonych z eksploatacji (SWE). *Journal of Translogistics*, Vol. 8, No. 18, pp. 113-128.
10. Olframalpa, <http://www.olframalpha.pl>, 15.09.2024.
11. Perzyński, T., Pietruszczak, D., Poneta, A. (2019). Pomiar hałasu pochodzącego od środków transportu drogowego w wybranych punktach miasta Radomia. *Autobusy*, No. 6, pp. 81-86.
12. Souza de Abreu, V.H., Santos, A. (2022). Climate Change Impacts on the Road Transport Infrastructure: A Systematic Review on Adaptation Measures. *Sustainability*, No. 1, pp. 1-22, doi.org/10.3390/su14148864.
13. Wisniewski, L.S. (2020). Emisje gazów cieplarnianych z transportu. miejska polityka transportowa i przestrzenna w obliczu zmian klimatu. *Acta Sci. Pol. Architectura*, Vol. 19, No. 4, pp. 73-88, doi: 10.22630/ASPA.2020.19.4.39.
14. Zhang, R., Fujimori, S. (2020). The role of transport electrification in global climate change mitigation scenarios. *Environmental Research Letter*, No. 15, pp. 1-12, doi: 10.1088/1748-9326/ab6658.

CREDIT POSITION OF LOGISTICS SECTOR COMPANIES IN POLAND IN THE CONTEXT OF MACROECONOMIC CONDITIONS

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Purpose: The research's main aim is to determine how the general macroeconomic situation (Macro) affects the credit position of the logistics sector.

Design/methodology/approach: Designed was a model based on the macroeconomic conditions indicator and credit position indicator. Spearman's rank was used to assess the relationship between the above indicators and the OLS regression to estimate the model. At the last stage, the Vector Auto-Regression model (VAR) was created. The research focuses on a group of enterprises from the Transportation and Storage (H) section, employing more than ten employees in Poland. The study covered the period from the beginning of the financial crisis (2008) to 2023. The data for the model is annual, and obtained from the Central Statistical Office database.

Findings: The analysis found that the macroeconomic conditions positively impact the credit position of enterprises in the logistics sector in Poland. Moreover, the credit position from the previous period positively impacts the credit indicator's value in the current year. In the logistics sector, throughout the analysed period, receivables from short-term supplies and services exceeded the value of liabilities (credit position indicator of the logistics sector in Poland > 1). During the COVID-19 pandemic, the Polish economy's synthetic macroeconomic indicator and the logistics sector's credit position indicator decreased.

Research limitations/implications: The research focused on the static approach to credit position. Further research will be dedicated to assessing the impact of internal and external factors on the credit position in a dynamic approach (based on the cycle of liabilities towards suppliers and the cycle of receivables from recipients) and then determining the differences between the static and dynamic approach in the context of macro social conditions.

Practical implications: The results of the analysis can support the managers of companies in making decisions aimed at trade credit granted and trade credit received in the context of the macroeconomic situation.

Originality/value: The study's novelty is to establish the relationship between the macroeconomic situation measured by the Macro indicator and the credit position of enterprises in the logistics sectors, with particular emphasis on the period of the COVID-19 pandemic.

Keywords: credit position, macroeconomic conditions, logistics sector.

Category of the paper: research paper.

1. Introduction

Understanding the complex relationship between macroeconomic factors and logistics performance is crucial in contemporary economy, facing many challenges nowadays and in recent decades (Ababou, Benomar, 2024). Conversely, efficient logistics system can foster economic growth and increase competitiveness of the given country (Mumin, Yakubu, 2023).

The importance of logistics sector companies in Poland in economic processes has increased significantly in recent years, which is also related to the development of logistics systems (Sadowski et al., 2020). A broadly defined transport system and warehousing, as well as their efficiency are considered as elements of the logistics system, within which processes are implemented in supply chains and logistics networks (Rudd, 2023; Richards, Grinsted, 2024).

According to the World Bank's Logistics Performance Index (LPI), ranging from 1 (worst) to 5 (best), which measures the effectiveness of logistics operations in given countries (efficiency of customs clearance process, quality of trade- and transport-related infrastructure, ease of arranging competitively priced shipments, quality of logistics services, ability to track and trace consignments, and frequency with which shipments reach the consignee within the scheduled time), the situation of Poland improved in years 2007-2022, from 3,04 in 2007, prior to financial crisis to 3,6 in 2022, in post-pandemic period (Arvis et al., 2023).

However, the macroeconomic conditions, such as: economic growth, measured by GDP, situation on the labor market, expressed in employment and unemployment rate, international trade (export and import) value and volume, as well as expenditures on investment, education and R&D and overall situation of public finance, measured by public sector debt, are the framework for economic activity of logistics sector companies (Muslija et al., 2021; Comporek et al., 2022). Moreover, the macroeconomic situation and all external factors have an impact on financial situation of enterprises in logistics sector, such as: credit position, financial liquidity and profitability, determining the possibilities of development and further existence on the market (Misztal, 2022).

The purpose of the research is to examine how the general macroeconomic situation, in the years 2008-2023, affects the credit position of the logistics sector companies in Poland, involved in Transportation and Warehousing. The most significant examples of breaking points, causing economic shock were global financial crisis in 2008 or the Covid-19 pandemic, started in 2020. Reduced demand on commodities and transport during the financial crisis, as well as disruptions in logistics or even broken supply chains due to the Covid-19 pandemics, were severe problems. Logistics sector had to face the challenge of demand volatility, e-commerce growth, shortage of employees and containers, congestion in ports, excessive freight and shipment cost and last but not least energy crisis (Xu et al., 2020; Moosavi et al., 2022).

2. Theoretical background

2.1. Macroeconomic indicators of logistics sector companies

The literature emphasizes the importance of considering macroeconomic factors in assessing performance of logistics sector companies (Orzukulova, 2022). Taking into consideration overall macro environment one can distinguish: politics, law, technological, demographic and other socio-economic conditions, which undoubtedly in the researched period, influenced logistics sector (Krykavskyy et al., 2023).

The macroeconomic environment plays a pivotal role in shaping logistics dynamics, as economic growth, investment flows, inflation rate, and trade openness interact with logistical infrastructure and operations (Delgado et al., 2012).

GDP, or Gross Domestic Product, serves as a fundamental measure in economics, quantifying the total value of goods and services produced within a country during a specific time period. It is widely utilized as an indicator of economic growth. However, its status as a sole measure of welfare and development faces debates and criticisms (Syrquin, 2016).

In the macroeconomic context, the impact of inflation will be felt by all companies in the logistics sector, affecting the performance of the capital market and causing high uncertainty. Inflation rates can have negative effects on the economy, including weakening the national currency, increasing the cost of imports, decreasing the purchasing power of individuals, and increasing credit costs and interest rates (Ababou, Benomar, 2024).

Foreign trade, defined as the sum of exports and imports of goods and services, measured as a share of gross domestic product, plays a crucial role in economies worldwide. International trade has been a vital part of civilizations for thousands of years, with motivations ranging from dire necessity to improving the quality of life (Reisman, 2023). Terms of trade for goods have generally increased over time, while the terms of trade for services have decreased, indicating a shift in comparative advantage from services to goods (Officer, 2022). Modern theories of international trade aim to explain the dynamics of trade and the changing structure and volumes of exports and imports.

Countries with higher levels of trade relative to GDP tend to invest more in trade facilitation measures, such as customs modernization and infrastructure development, leading to smoother cross-border trade and enhanced logistics efficiency (Arvis et al., 2018).

A deeper understanding of the elements contributing to a country's logistics performance can enhance freight transport and warehousing efficiency and reveal underlying challenges, making monitoring trade and logistics performance imperative for uncovering areas in need of improvement. The exploration of the relationship between macroeconomic factors and logistics performance reveals several significant gaps in existing literature that warrant further investigation.

2.2. Trade credit approach and a credit position of an enterprise

Trade credit is an arrangement between a seller and a buyer allowing an exchange of goods with deferred payment terms (Martinez-Sola et al., 2013). It is a short-term cash management tool wherein a firm can simultaneously act as a supplier and user of the trade credit. Trade credit, when it appears on the assets side of the balance sheet, is called accounts receivables (trade credit granted). When trade credit appears on the liability side, it is called accounts payable (trade credit received) (Boyer, Gobert, 2009). For a firm, it is important to extend trade credit to sell its goods to its customers, but it is also important to receive trade credit from its suppliers to finance production.

The trade credit can be characterised as highly diverse relationships operating under various market and off-market factors. Several mutually non-exclusive theories point to four major motives behind trade credit use: financial motive, element of competitive strategy, transaction cost reduction and quality control/signalling (Ciżkowicz-Pękała, 2017). Adopting a more comprehensive approach, we can indicate that the trade credit issue extends beyond a purely financial perspective. Trade credit management can be regarded as a relational activity affected by the level of the credit team's skills and awareness, communication of credit information, the structural position of the activity in the firm (Boden, Paul, 2014) and managerial ability (James et al., 2023). Research proves that cultural factors, such as trust, religion, and national culture, also play important roles in the provision and receipt of trade credit (Ziętek-Kwaśniewska, 2023).

A multi-faceted approach to the issue of trade credit and a diverse approach to the factors shaping its development result in research development in this area. However, there is an important gap in this research. It refers to the impact of macroeconomic conditions on the creation of the credit position of enterprises. This position is measured using a credit position indicator calculated as the relationship between receivables from recipients (receivables resulting from deliveries and services) and liabilities towards suppliers (liabilities resulting from deliveries and services) (Sierpińska, Wędzki, 2023).

Depending on the value of this ratio, two forms of credit position can be distinguished:

- trade credit recipient's position (credit position indicator <1),
- trade credit provider's position (credit position indicator >1).

The analysis of this indicator is important, among other things, because its level is associated with the risk of bankruptcy. Research findings show that in the period leading up to and in the year of bankruptcy, enterprises were usually in the position of trade credit recipient (Kowalik, 2021). The above issue becomes particularly important in the context of the growing problem of insolvency of Polish enterprises, especially companies from the logistics sector (Raport Coface..., 2024).

Research shows that the level of trade credit is influenced by macro indicators and the economic climate (Kumar, Shrivastava, 2013; Kumar et al., 2021), but there are no studies on the influence of macroeconomic situation on the credit position of enterprise, especially in the logistics sector. In case of deteriorating gross domestic product, non-financial firms practice more deferred payment sales (Ahmed et al., 2015; Kumar et al., 2021) but also increase the use of trade credit (Niskanen, Niskanen, 2006). Therefore, during a downturn or financial crisis, trade credit management may have a key impact on the company's liquidity, profitability, and financial security. Research proves that there is a significant connection between trade credit policy and the cash flows (Molina, Preve, 2009; Kumaraswamy, 2019), profitability of enterprise (Kumar, Shrivastava, 2013; Hoang et al., 2019) and also firm's value (Shahzad et al., 2022), growth in sales (Lefebvre, 2023). Therefore, proper trade credit management may be crucial for enterprises' survival and development, especially during financial crises or the COVID-19 pandemic. Research showed that the pandemic outbreak forced changes in trade credit management. The decrease in receivables from customers and the maintenance of the previous level of liabilities resulted in a decrease in the credit position indicator (Zimon, Dankiewicz, 2020).

3. Research methodology

Our research focuses on a group of enterprises from the Transportation and Storage (H) section, employing more than ten employees in Poland. The study period covered the period from the beginning of the financial crisis (2008) to 2023 (due to the availability of statistical data). The data for the model is annual, and it was retrieved from the Central Statistical Office database.

The research's main aim is to determine how the general macroeconomic situation (Macro) affects the credit position of the logistics sector. In connection with this goal, the following research hypothesis was formulated: *Macroeconomic conditions positively impacted the credit position of the logistics sector in Poland from 2008 to 2023* ($p < 0.05$). Additionally, the following research questions were asked:

- What is the trend of the credit position indicator of enterprises?
- What is the general macroeconomic situation in Poland?
- Has the COVID-19 pandemic negatively affected the credit position of the logistics sector?

To verify the research hypothesis, created were a macroeconomic conditions indicator (Macro) and credit position indicator of the logistics sector ($CredP_0$).

The Macro indicator was developed based on stimulants (GDP per capita, employment, education expenditure, R&D expenditure, investment expenditure, export) and destimulants (unemployment rate, import, public sector debt). The following formulas were used:

$$Macro_{ij} = \frac{\sum_{i=1}^n \frac{x_{ij}}{\max x_{ij}} + \sum_{i=1}^n \frac{\min x_{ij}}{x_{ij}}}{n}; Macro_{ij} \in [0; 1] \quad (1)$$

where:

$Macro_{ij}$ – the normalized value of the j-th variable in the i-th year;

x_{ij} is the value of the j-th variable in the i-th year;

n is the number of metrics.

$$Cred_{Po} = \frac{Rec}{Pay} \quad (2)$$

where: $Cred_{Po}$ – logistics sector credit position; Rec-short-term trade receivables; Pay- short-term trade payables.

To assess the relationship between the Macro and $Cred_{Po}$ indicators, used was the Spearman's rank, which was determined based on the following formula:

$$r_s = \frac{\frac{1}{6}(n^3 - n) - (\sum_{i=1}^n d_i^2) - T_x - T_y}{\sqrt{\left(\frac{1}{6}(n^3 - n) - 2T_x\right) \left(\frac{1}{6}(n^3 - n) - 2T_y\right)}}, \quad (3)$$

$$d_i = Rx_i - Ry_i; T_x = \frac{1}{12} \sum_j (t_j^3 - t_j); T_y = \frac{1}{12} \sum_k (u_k^3 - u_k)$$

where:

t_j is the number of observations in the sample having the same j-th rank value of the variable x;

u_k is the number of observations in the sample having the same k-th rank value of the variable y;

R_x is the ranks of x in the sample;

R_y is the ranks of y in the sample.

Created was also an equation based on formula:

$$Cred_{Posi} = \beta_0 + \beta_1 \cdot Macro_i + \varepsilon_i; \quad (4)$$

the residual for each observation is as follows:

$$e_i = Cred_{Po i} - (\hat{\beta}_0 + \hat{\beta}_1 Macro_i) \quad (5)$$

Used was the OLS regression to estimate model:

$$s(\hat{\beta}_0, \dots, \hat{\beta}_6) = \sum_{i=1}^n (Cred_{Po i} - \hat{\beta}_0 - \hat{\beta}_1 Macro_i - e_i)^2 \rightarrow \min \quad (6)$$

Model tests: White's test for heteroskedasticity; Frequency distribution for residual; Breusch-Godfrey test for first-order autocorrelation; the variance inflation factor (VIF).

In the last stage, built was the Vector Auto-Regression model (VAR) to check:

$$Cred_{p_o t} = \sum_{i=1}^{np} (A_i Cred_{p_o} - i + E_t) \quad (7)$$

where:

$Cred_{p_o t}$ - vector of values of the analyzed processes at time t (including all variables in the model),

A_i - matrix of parameters with delays of variables from vector $Cred_{p_o}$,

E_t - vector of stationary random disturbances.

4. Research results

Figure 1 shows the research sample, i.e. the number of enterprises in the Transportation and Storage section employing more than ten employees in Poland from 2008 to 2023. The number of enterprises in the period under study is increasing, and the trend is positive.

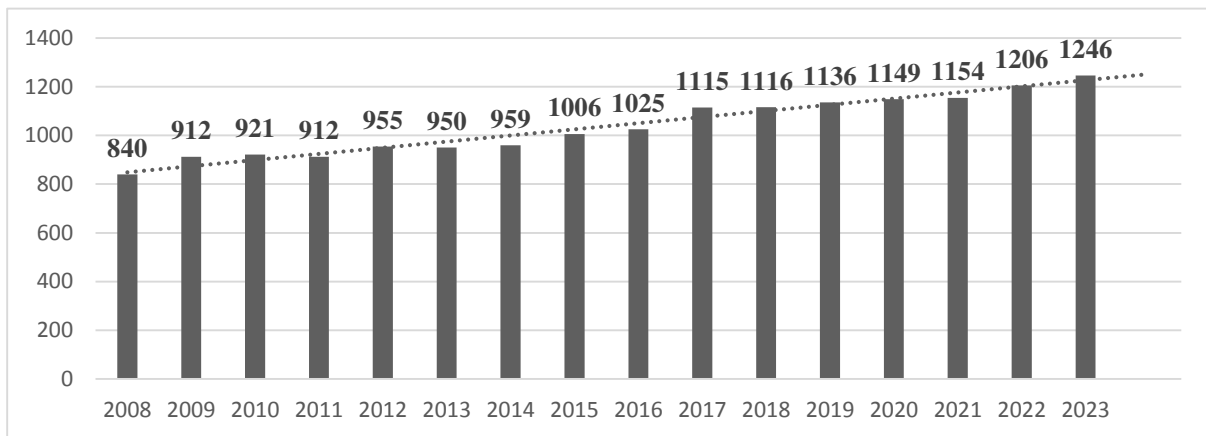


Figure 1. Number of enterprises in logistics sector in Poland (research sample).

Source: <https://bdl.stat.gov.pl/bdl/dane/podgrup/tablica>.

The credit position indicator is presented in Figure 2. It exceeds the value of 1 throughout the period, which means that short-term trade receivables exceed the value of short-term trade payables. It should be noted that the value of the indicator fluctuates slightly.

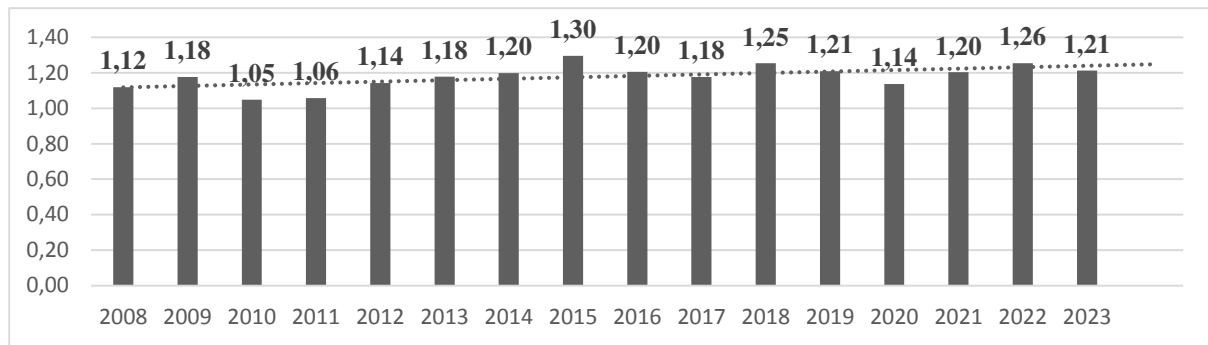


Figure 2. Credit position indicator of logistics sector in Poland.

Source: <https://bdl.stat.gov.pl/bdl/dane/podgrup/tablica>.

Figure 3 shows the macroeconomic conditions index. The indicator trend is positive, which should be assessed positively from the point of view of the economic situation in Poland. The only year in which the index decreased from year to year was 2020, i.e., during the COVID-19 pandemic, when there were temporary restrictions on conducting business activities.

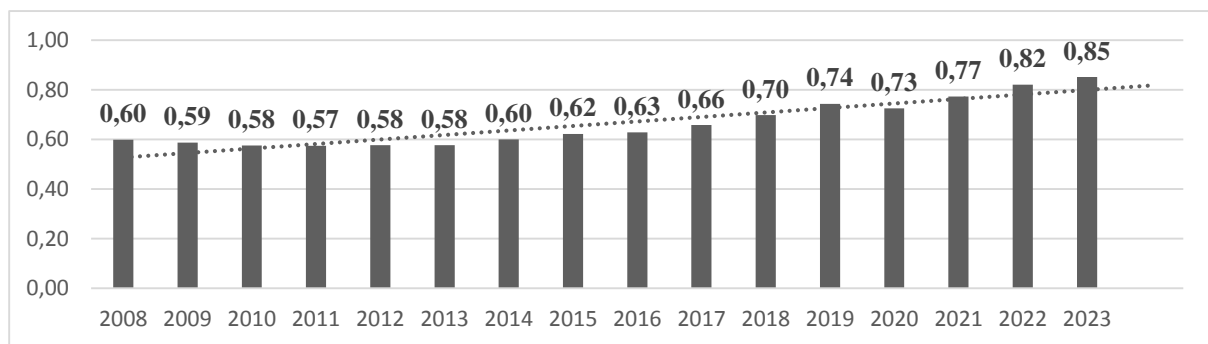


Figure 3. Synthetic macroeconomic indicator of Polish economy.

Source: <https://strateg.stat.gov.pl/#/wyszukaj-wskaznik/4282>.

The Spearman rank correlation coefficient was 0.5, which means the average correlation between the credit position of logistics sector enterprises and macroeconomic conditions in Poland from 2008 to 2023 (Table 1).

Table 1.

The OLS estimation Correlation coefficients, using the observations 1-16; 5% critical value (two-tailed) = 0.4973 for $n = 16$

CredPo	Macro	
1.0000	0.4919	CredPo
	1.0000	Macro

Source: own calculations based on <https://bdl.stat.gov.pl/bdl/dane/podgrup/tablica>; <https://strateg.stat.gov.pl/#/wyszukaj-wskaznik/4282>.

Table 2 shows the results of the Ordinary Least Square estimation. At the statistical significance level of $p < 0.05$, macroeconomic conditions positively impact the logistics sector's credit position, i.e. the tendency of enterprises to credit customers to a greater extent than to use credit from suppliers. Therefore, a unit increase in the macroeconomic conditions index

will lead to a 0.35 increase in the credit position index of enterprises. However, the low level of R2 should be noted.

Table 2.

The OLS estimation: dependent variable: Static credit position

	Coefficient	Std. Error	t-ratio	p-value	
Const	0.945784	0.111668	8.470	<0.0001	***
Macro	0.352600	0.166796	2.114	0.0529	*

Mean dependent var	1.179678		S.D. dependent var	0.067034
Sum squared resid	0.051094		S.E. of regression	0.060412
R-squared	0.241967		Adjusted R-squared	0.187821
F(1, 14)	4.468845		P-value(F)	0.052946
Log-likelihood	23.27036		Akaike criterion	-42.54073
Schwarz criterion	-40.99555		Hannan-Quinn	-42.46160
Rho	0.353134		Durbin-Watson	1.260251

White's test for heteroskedasticity: LM = 1.42948 with p-value = $P(\text{Chi-square}(2) > 1.42948) = 0.489318$

Test for normality of residual: Chi-square(2) = 2.14776 with p-value = 0.34168

LM test for autocorrelation up to order 1: LMF = 1.83931 with p-value = $P(F(1, 13) > 1.83931) = 0.198121$

Source: own calculations based on <https://bd1.stat.gov.pl/bd1/dane/podgrup/tablica>; <https://strateg.stat.gov.pl/#/wyszukaj-wskaznik/4282>.

The analysis is supplemented by the first-degree Autoregression model (due to the short research period, we used a one-period delay) (Table 3). The results of VAR estimation indicate that the credit position from the previous period has a positive impact on the indicator's value in the current year. Thus, the credit policy and its conditions are continuous and related to the investment implementation process in the sector.

Table 3.

The VAR system, lag order 1: dependent variable: Static credit position

Log-likelihood = 21.567078					
Determinant of covariance matrix = 0.00330114					
AIC = -2.6089					
BIC = -2.5145					
HQC = -2.6099					
	Coefficient	Std. Error	t-ratio	p-value	
const	0.641821	0.282935	2.268	0.0410	**
CredPo_1	0.460224	0.239921	1.918	0.0773	*

Mean dependent var	1.183694		S.D. dependent var	0.067365
Sum squared resid	0.049517		S.E. of regression	0.061717
R-squared	0.220605		Adjusted R-squared	0.160652
F(1, 13)	3.679612		P-value(F)	0.077312
rho	0.050747		Durbin-Watson	1.890162

Source: own calculations based on <https://bd1.stat.gov.pl/bd1/dane/podgrup/tablica>; <https://strateg.stat.gov.pl/#/wyszukaj-wskaznik/4282>.

5. Discussion and conclusion

Credit position is important for an enterprise's proper functioning and development. Therefore, maintaining appropriate relations between receivables from deliveries and services and liabilities from supplies and services is crucial for the financial situation of enterprises and their development prospects (Kowalik, 2021).

The credit position of enterprises is conditioned by several factors related to the financial and property situation of enterprises, the style and model of financial management, and external factors on which enterprises have a very limited influence. Such an exemplification are macroeconomic conditions, the improvement of which is also an impulse for the development of the enterprise sector (Oladimeji et al., 2021; Niedźwiedzińska, Kowalska, 2020; Njegomir, Radović, 2018).

The research hypothesis put forward at the beginning of the study indicating that macroeconomic conditions positively impacted the credit position of the logistics sector in Poland from 2008 to 2023 ($p < 0.05$) is true. Therefore, the main macroeconomic indicators should be analyzed when analyzing the situation of the logistics sector and the prospects for its development. The credit position of the logistics sector in Poland from 2008 to 2023 exceeds the value of one. It means that the tendency of logistics sector enterprises to finance recipients to a greater extent than financing from suppliers is increasing. This situation may be related to the activities of enterprises in this sector aimed at increasing sales (larger amounts of trade credit granted, longer trade credit periods for recipients), but on the other hand, it creates a need for additional capital - that is consistent with the results of other studies (Ahmed et al., 2015; Kumar et al., 2021, Niskanen, Niskanen, 2006).

The analysis showed that problems with late payments and backlogs in Polish enterprises depend highly on macroeconomic variables (Woźniak et al., 2019). The conducted research also shows that the macroeconomic situation influences the trade credit position in the logistics sector. The macroeconomic conditions indicator is also increasing. A high growth rate characterizes the trend, so one deals with positive changes in the Polish economy throughout the period under review.

The COVID-19 pandemic affected negatively the socio-economic conditions of Poland, it has also weakened the situation of the logistics sector. Observed was a decrease in the credit position indicator, also noticeable in other sectors during the COVID-19 pandemic (Zimon, Dankiewicz, 2020). However, it should be noted that already in the second year, there were signs of recovery and an increase in the credit position indicator of enterprises.

The study has certain limitations related to, for example, the method of calculating the credit position indicator. It was limited only to the static position. Moreover, selecting analytical indicators to create a synthetic indicator of macroeconomic development also affects the estimation results. It should also be noted that applying the conditions for OLS estimation is necessary, which also means this method has certain limitations.

Further research will be devoted to assessing the impact of internal and external factors on the credit position in a dynamic approach (based on the cycle of liabilities towards suppliers and the cycle of receivables from recipients) and then determining the differences between the static and dynamic approach in the context of macro social conditions.

References

1. Ababou, M., Benomar, I. (2024). Insights into the Interplay Between Macroeconomic Factors and Logistics Performance Index. *Journal of Namibian Studies*, 40, pp. 413-435, doi: <https://doi.org/10.59670/jsf7q813>.
2. Ahmed, J., Xiaofeng, H., Mujtaba, G. (2015). Effects of Firm Specific and Macro-Economic Factors on Trade Credit Supply: The Case of a Developing Country. *International Journal of Financial Management*, 5(1), pp. 18-26, doi:10.21863/ijfm/2015.5.1.004
3. Arvis, J.-F., Ojala, L., Shepherd, B., Ulybina, D., Wiederer, C. (2023). Connecting to Compete 2023: Trade Logistics in an Uncertain Global Economy - The Logistics Performance Index and Its Indicators. Washington: World Bank, doi:10.1596/39760.
4. Boden, R., Paul, S.Y. (2014). Creditable behaviour? The intra-firm management of trade credit. *Qualitative Research in Accounting & Management*, 11(3), pp. 260-275, doi: <http://dx.doi.org/10.1108/QRAM-08-2012-0032>.
5. Boyer, M.M., Gobert, K. (2009). The impact of switching costs on vendor financing. *Finance Research Letters*, 6(4), pp. 236-241, doi: <https://doi.org/10.1016/j.frl.2009.07.001>.
6. Cizkiewicz-Pękała, M. (2017). Trade credit: A benefit to get, a “must” to give? Motives behind trade credit use in Poland. *Financial Internet Quarterly*, 13(4), pp. 54-66, doi: <https://doi.org/10.1515/fiqf-2016-0035>.
7. Comporek, M., Kowalska, M., Misztal, A. (2022). Macroeconomic stability and transport companies' sustainable development in the Eastern European Union. *Journal of Business Economics and Management*, 23(1), pp. 131-144, doi: 10.3846/jbem.2021.15913.
8. Delgado, M., Ketels, C., Porter, M.E., Stern, S. (2012). *The Determinants of National Competitiveness* (No. w18249). National Bureau of Economic Research.
9. Hoang, H., C., Xiao, Q., Akbar, S. (2019). Trade credit, firm profitability, and financial constraints. *International Journal of Managerial Finance*, 15(5), pp. 744-770, doi: 10.1108/IJMF-09-2018-0258.
10. James, H., L., Ngo T., Wang H. (2023). The impact of more able managers on corporate trade credit. *Journal of Behavioral and Experimental Finance*, vol. 40, doi: <https://doi.org/10.1016/j.jbef.2023.100857>.

11. Kowalik, M. (2021). Enterprise Credit Position and the Risk of Bankruptcy. *Zeszyty Naukowe Uniwersytetu Ekonomicznego w Krakowie*, 1(991), pp. 23-36, <https://doi.org/10.15678/ZNUEK.2021.0991.0102>.
12. Krykavskyy, Y., Shandrivska, O., Pawłyszyn, I. (2023). A Study of Macroeconomic and Geopolitical Influences and Security Risks in Supply Chains in Times of Disruptions. *LogForum*, 19(3), p. 423, doi: 10.17270/J.LOG.2023.855.
13. Kumar, N., Shrivastava, A., Kumar, P., Bhatt, M.I. (2021). An Analysis of Trade Credit Behaviour of Indian Firms. *South Asia Economic Journal*, 22(1), pp. 132-154, doi: 10.1177/13915614211009659.
14. Kumar, P., Shrivastava, A. (2013). Trade credits and corporate profitability: Some empirical findings in Indian context. *Journal of Management Value & Ethics*, 3(3), pp. 41-57.
15. Kumaraswamy, S., George, S. (2019). Trade credit management and firm profitability of Saudi manufacturing firms. *Polish Journal of Management Studies*, 20(1), pp. 243-253, doi: 10.17512/pjms.2019.20.1.22.
16. Lefebvre, V. (2023). Trade credit, payment duration, and SMEs' growth in the European Union. *International Entrepreneurship and Management Journal*, vol. 19, pp. 1313-1340, doi: <https://doi.org/10.1007/s11365-023-00871-4>.
17. Martinez-Sola, C., García-Teruel, P.J., Martinez-Solano, P. (2013). Corporate cash holding and firm value. *Applied Economics*, 45(2), pp. 161-170, doi: 10.1080/00036846.2011.595696.
18. Misztal, A. (2022). Profitability, Financial Liquidity and the Sustainable Development of Manufacturing Enterprises in Poland. *Studies in Law and Economics*, 125, pp. 121-139.
19. Molina, C.A., Preve, L.A. (2009). Trade receivables policy of distressed firms and its effect on the costs of financial distress. *Financial Management*, 38(3), pp. 663-686, doi: <https://doi.org/10.1111/j.1755-053X.2009.01051.x>.
20. Moosavi, J., Fathollahi-Fard, A.M., Dulebenets, M.A. (2022). Supply chain disruption during the COVID-19 pandemic: Recognizing potential disruption management strategies. *International Journal of Disaster Risk Reduction*, 75, doi:10.1016/j.ijdrr.2022.102983.
21. Mumin, M.A., Yakubu, I.N. (2023). Beyond Supply Chains: Investigating the Economic Impact of Logistics Performance. *Journal of International Business, Economics and Entrepreneurship*, 8(2), pp. 7-16, doi: <https://doi.org/10.24191/jibe.v8i2.24246>.
22. Muslija, A., Džemal, C., Šahić, A. (2021). The relationship between economic growth and logistics sector in the case of G-7 countries. *Transportation Research Procedia*, 55, pp. 326-333, doi: <https://doi.org/10.1016/j.trpro.2021.06.038>.
23. Niedźwiedzińska, H., Kowalska, M.K. (2020). Evaluation of the impact of macroeconomic factors on innovativeness of enterprises from the TSL sector in the countries of Central and Eastern Europe. *Optimum Economic Studies*, 99(1), pp. 34-47, doi:10.15290/oes.2020.01.99.03

24. Niskanen, J., Niskanen, M. (2006). The Determinants of Corporate Trade Credit Policies in a Bank-dominated Financial Environment: the Case of Finnish Small Firms. *European Financial Management*, 12(1), pp. 81-102, doi: <https://doi.org/10.1111/j.1354-7798.2006.00311.x>.
25. Njegomir, V., Radović, M. (2018). Analysis of the impact of macroeconomic environment on the entrepreneurship development. *Poslovna Ekonomija*, 12(2), pp. 1-19 doi: 10.5937/poseko14-18713.
26. Officer, L.H. (2022). *Terms of Trade. In Essays in Economic History: Purchasing Power Parity, Standard of Living, and Monetary Standards*. Cham: Springer International Publishing, pp. 157-172.
27. Oladimeji, M.S., Sofoluwe, N.A., Odunaya, H.A. (2021). Macroeconomic Business Environment and the Development of Small and Medium Enterprises in Nigeria. *Modern Management Review*, 26(4), pp. 93-105, <https://doi.org/10.7862/rz.2021.mmr.27>.
28. Orzukulova, Z. (2022). Macroeconomic Indicators of the Efficiency of Transport Logistics Services and Ways of Their Determination. *Research And Education*, 1(9), pp. 521-525.
29. *Raport Coface: Niewypłacalności w Polsce po I półroczu 2024 r.* Retrieved from: <https://www.coface.pl/publikacje-ekonomiczne-i-analizy/raport-coface-niewypłacalnosci-w-polsce-po-i-polroczu-2024-r>, 20.10.2024.
30. Reisman, D. (2023). *Goods and Services. In Global Political Economy*. Edward Elgar Publishing, pp. 69-94.
31. Richards, G., Grinsted, S. (2024). *The logistics and supply chain toolkit: over 100 tools for transport, warehousing and inventory management*. London: Kogan Page Publishers.
32. Rudd, J. (2023). *A Practical Guide to Logistics: An Introduction to Transport, Warehousing and Distribution*. London: Kogan Page Publishers.
33. Sadowski, A., Wąsowska, K., Nowak, I. (2020). Logistics development in European countries: The case of Poland. *European Research Studies*, 23(2), pp. 500-514, doi: 10.35808/ersj/1606.
34. Shahzad, U., Zhaob, L., Liuc, J., Luo, F. (2022). Corporate value and trade-credit policies: evidence from China. *Journal of Applied Economics*, 25(1), pp. 412-432, doi: <https://doi.org/10.1080/15140326.2022.2045467>.
35. Sierpińska, M., Wędzki, D. (2023). *Zarządzanie płynnością finansową w przedsiębiorstwie*. Warszawa: PWN.
36. Syrquin, M. (2016). A Review Essay on GDP: A Brief but Affectionate History by Diane Coyle. *Journal of Economic Literature*, 54(2), pp. 573-588.
37. Woźniak, D., Sokołowska-Woźniak, J., Jankowiak, B., Cwynar, A., Cwynar, W., Ostrowska-Dankiewicz, A., Dankiewicz, R. (2019). Trade Credit in Polish Companies. An Empirical Analysis of Macroeconomic Factors Influencing Payment Delays. *Business and Non-profit Organizations Facing Increased Competition and Growing*

- Customers' Demands*, vol. 17, pp. 627-644. <http://bazekon.icm.edu.pl/bazekon/element/bwmeta1.element.ekon-element-000171528792>
38. Xu, Z., Elomri, A., Kerbache, L., El Omri, A. (2020). Impacts of COVID-19 on Global Supply Chains: Facts and Perspectives. *IEEE Engineering Management Review*, 48(3), pp. 153-166, doi: 10.1109/EMR.2020.3018420.
39. Ziętek-Kwaśniewska, K. (2023). Cultural aspect of the use of trade credit. *Zeszyty Naukowe Politechniki Śląskiej. Organizacja i Zarządzanie*, no. 182, pp. 695-711, doi: <http://dx.doi.org/10.29119/1641-3466.2023.182.41>
40. Zimon, G., Dankiewicz, R. (2020). Trade Credit Management Strategies in SMEs and the COVID-19 Pandemic — A Case of Poland. *Sustainability*, 12(15), 6114; doi:10.3390/su12156114.

ORGANIZATION OF THE EMERGENCY MEDICAL SERVICE IN POLAND

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Purpose: The purpose of the article is to present the organization and financing of the emergency medical services system in Poland, against the background of model solutions in this matter.

Design/methodology/approach: The methodology of the study is based on the analysis of existing legal regulations on the organization of the emergency medical services system in Poland. A review of the available literature, in which the authors addressed issues related to models of functioning of the emergency medical services system, was also carried out. Statistical data provided by the Statistics Poland (GUS) and reports on the implementation of the financial plan provided by the National Health Fund (NFZ) were reviewed.

Findings: The State Emergency Medical Service system is evolving towards the Anglo-American model. The previous model of financing through a subsidy from the state budget has proved insufficient. In the years under review (2007-2022), the subsidy was insufficient to cover the costs of operating the State Emergency Medical Service. After a change in the method of financing, the burden of covering operating costs was transferred to the National Health Fund. In 2023, costs were planned to be higher than they were actually incurred. Year after year, however, the system requires higher expenses.

Originality/value: The publication addresses issues related to the organization of state emergency medical services in Poland. The subject matter is relevant in the context of the current socio-economic and political situation and is a contribution to further in-depth research in a situation of shortage of resources allocated to health care.

Keywords: emergency medical service, organization, financing, model of EMS delivery.

Category of the paper: research paper.

1. Introduction

In Poland, the State Emergency Medical Service system was created to provide necessary medical assistance to people who are in a state of sudden danger to life or health. This system is critical to the sense of security in both individual situations and mass events. The provision of medical assistance in situations and states of sudden danger to life and health is guaranteed by Article 68 of the Constitution of the Republic of Poland. The law governing the organization

of the EMS system, the principles of its financing and operation has been undergoing evolution. The first law on State Emergency Medical Services was passed on July 25, 2001. It was in force until December 31, 2006 (Journal of Laws No. 113, item 1207). It was replaced by the current Law on State Emergency Medical Services (Journal of Laws 2006 No. 191, item 1410). In connection with the need to achieve increasingly higher efficiency, the organization of the Emergency Medical Service system is changing. Significant changes in the organization of the system, aimed at improving the functioning of the entire Emergency Medical Service system, were introduced by the Act of May 10, 2018 amending the Law on State Medical Rescue and certain other acts (Journal of Laws 2018 item 1115). The purpose of the article is to present the organization of the Emergency Medical Service system in Poland, against the background of model solutions.

2. Organization of the State Emergency Medical Service system

The World Health Organization (WHO) defines Emergency Medical Service system (EMS) as a way of deploying personnel, equipment and technical facilities to ensure proper, effective and coordinated system activities including preventive actions, management of risks arising from emergencies, disasters, natural disasters, etc. Their task is to provide medical care services implemented at the scene of an incident and during transport (pre - hospital EMS) and hospital emergency medicine services (in-hospital EMS) implemented in emergency departments. (Kuehl, 2002; WHO, 2008; Bem, 2013). According to this definition, the emergency medical system should provide medical care to the patient at the scene, during transport to the nearest hospital and in the hospital.

The way of the delivery of service depends on the model in which emergency medical services operate. Since the 1970s, the organization of emergency medical services in the pre-hospital setting has been based on two main models: the Anglo-American and the Franco-German models (Al-Shaqsi, 2010; Chenaitia et al., 2011).

The Franco-German model, is the idea of bringing the hospital closer to patients, based on the principle of *stay and stabilize*. Medical activities are carried out by experienced doctors who are authorized to make complex clinical assessments and treat patients in their homes or at the scene. As a result, fewer people are transported to hospitals. The few patients transported to medical facilities are usually admitted directly to hospital wards by an emergency medicine field physician, bypassing the emergency department (Roessler, Zuzan, 2006; Adnet, Lapostolle, 2004; Spiteri, 2008).

The Anglo-American model, on the other hand, works in countries where emergency medicine is well developed and widely recognized as a separate medical specialty. It is based on the principle of *scoop and run* (Al-Shaqsi, 2010; Dijkink et al., 2017; Bélanger et al., 2019;

Makrides et al., 2022). This means getting patients to the hospital quickly with fewer pre-hospital interventions. In this model, paramedics are closer to public safety services, such as police or firefighters, rather than health care (Pozner et al., 2004). Trained paramedics and emergency medical technicians (EMTs) operate the system under clinical supervision. On-scene and transport services tend to be reduced to basic emergency services. Patients are transported mainly in ambulances, with less use of air-medical evacuation or coastal ambulance. Nearly all patients in the Anglo-American model are transported by Emergency Medical Services personnel to developed emergency departments rather than to hospital wards (Al-Shaqsi, 2010; Bélanger et al., 2019; Makrides et al., 2022).

Sharp distinctions between these models were evident from the 1970s until the end of the 20th century. Today, most EMS systems around the world have components of both models. In Poland, EMS is largely based on the Anglo-American model adapted to Polish conditions. It is also recognized that the Anglo-American model is the most effective and modern model for the organization and operation of emergency medical services (McConnell et al., 2007). In addition, EMS in Poland is based on the standards of the golden hour (the time within which a person in a life-threatening condition should be delivered to a facility where medical assistance can be provided) and the concept of the chain of survival (the chain of survival consists of early recognition of cardiac arrest and call for help - early initiation of cardiopulmonary resuscitation - early defibrillation - post-resuscitation care; the first three links can be taken care of by a pre-medical first aider, the last belongs to hospital care) (Andres, 2022; Miłowski et al., 2024).

According to the provisions of the Law on State Emergency Medical Services (Journal of Laws, No. 191, item 1410), the State Emergency Medical Services system consists of government administrative bodies responsible for carrying out the tasks of the system, namely the minister in charge of health and the provincial governors. Supervision of the system in the country is exercised by the minister responsible for health, while the task of the governor is to organize, plan, coordinate and supervise the execution of the system's tasks (Article 18 of the Law on State Emergency Medical Services, Journal of Laws 2006, No. 191, item 1410).

The second branch is the cooperating units of the system: medical dispensaries, hospital emergency departments, emergency medical service teams and air ambulance services.

Medical dispensaries are organizational units of the provincial office, which are listed in the provincial plan of operation of the EMS system, established to receive and handle emergency calls transmitted from emergency notification centers (Article 3(2) of the Law on Emergency Notification System, Journal of Laws 2023, item 748)), receive notifications of incidents and perform tasks by medical dispatchers (Article 3 of the Law on State Emergency Medical Services, Journal of Laws 2006, No. 191, item 1410).

Emergency medical teams are units of the EMS system, undertaking medical emergency activities in out-of-hospital settings. A distinction is made between specialized and basic teams. Specialized teams consist of at least three persons authorized to perform medical emergency

actions, including a system physician and a system nurse or paramedic. Basic teams, on the other hand, consist of at least two people authorized to perform medical emergency activities, including a system nurse or paramedic. Emergency medical service teams may also include a driver, in the event that none of the team members meet the conditions of the Law on Driving as specified in Article 106, paragraph 1 (Journal of Laws 2011, No. 30, item 151).

Air Ambulance, as a unit of the system, has three types of teams. These are EMS teams - an airplane or helicopter transport team with a crew consisting of two pilots, an EMT (paramedic or nurse). Airborne HEMS (Helicopter Emergency Medical Service) teams, on the other hand, consist of a pilot, a rescuer (paramedic or nurse) and a doctor (LPR).

Trauma centers and organizational units of specialized hospitals providing essential emergency medical services in the provincial plan of action of the system cooperate with the system. Also cooperating with the system are other units, such as the Police, Fire Department, Border Guard, mountain and water rescue (Article 2 of the Law on State Emergency Medical Services, Journal of Laws 2006, No. 191, item 1410).

In the State Emergency Medical Service system in 2023, there were 1617 teams in operation, including 1302 basic teams and 315 specialized teams. Since 2020, the number of working EMS teams has increased by 36 nationwide, while their structure has changed. The number of specialized teams was reduced by 28, while the number of basic teams was increased by 64. The most visible change took place in the Silesian province, where 13 specialized teams were dropped and 17 basic teams were established (Table 1). Thus, the tendency to move away from specialized teams (as in the Franco-German model) to basic teams (as in the Anglo-American model) is evident. Despite these changes, emergency teams most often provide out-of-hospital medical assistance to people in medical emergencies. In 2023, nearly 2.8 million trips or outings were made, of which 6.1% were to people under the age of 18, and 50.1% to people 65 and older. A significant percentage of the actions (77.1%) were those made to the patient's home. In addition to emergency medical service teams, medical assistance is also provided by air medical rescue teams from 21 Air Ambulance bases, and 246 hospital emergency departments.

In 2023, there were 155 emergency rooms, 17 trauma centers and 11 pediatric trauma centers working with the National Emergency Medical Service system. Nearly 4.0 million people received ambulatory (non-hospitalized) medical care in hospital emergency departments or emergency rooms, of whom children accounted for 19.5% and people aged 65 plus accounted for 26.8%.

Table 1.*Units of the State Emergency Medical System in 2020 and in 2023*

Province	Specialized emergency medical service teams			Basic emergency medical service teams			Hospital emergency rooms			Air Ambulance Teams	
	Year		Number	Year		Number	Year		Number	Year	
Year	2020	2023	change	2020	2023	change	2020	2023	change	2020	2023
Dolnośląskie	27	27	0	90	90	0	16	15	-1	1	1
Kujawsko-pomorskie	12	12	0	81	82	+1	10	11	+1	1	1
Lubelskie	28	28	0	65	65	0	17	16	-1	1	1
Lubuskie	11	8	-3	43	47	+4	8	8	0	2	2
Łódzkie	23	21	-2	80	83	+3	20	21	+1	1	1
Małopolskie	21	21	0	113	115	+2	21	21	0	1	1
Mazowieckie	41	37	-4	159	177	+18	31	33	+2	3	3
Opolskie	12	12	0	32	32	0	7	7	0	1	1
Podkarpackie	17	14	-3	78	83	+5	14	14	0	1	1
Podlaskie	20	20	0	37	37	0	12	13	+1	2	2
Pomorskie	20	19	-1	74	80	+6	13	13	0	1	1
Śląskie	41	28	-13	122	139	+17	14	15	+1	1	1
Świętokrzyskie	9	9	0	40	41	+1	10	11	+1	1	1
Warmińsko-mazurskie	12	12	0	69	70	+1	11	12	+1	1	1
Wielkopolskie	34	32	-2	88	94	+6	25	26	+1	2	2
Zachodniopomorskie	15	15	0	67	67	0	10	10	0	1	1
Total:	343	315	-28	1238	1302	64	239	246	7	21	21

Source: own compilation based on GUS (2021) and GUS (2024).

Emergency medical service teams in 2023 included nearly 12.9 thousand employees, the largest group of which were paramedics (more than 11.2 thousand). The teams included more than 0.3 thousand emergency medical system doctors, 1 thousand emergency medical system nurses, and 0.3 thousand drivers and pilots. Compared to 2020, the number of medical personnel included in the emergency medical service teams decreased slightly, as at that time there were 13.0 thousand employees in the emergency medical service teams. The largest group (11.0 thousand) were paramedics, in addition, almost 0.5 thousand system doctors, more than 1.1 thousand system nurses and 0.4 thousand drivers and pilots worked in the teams. Thus, the number of paramedics increased, while the number of doctors, system nurses, pilots and drivers decreased (GUS, 2021, 2024).

3. Financing of the State Emergency Medical Services system

Until the end of 2022, prehospital emergency medical services pertaining to the EMS system were financed from the state budget, from the parts administered by the Minister of Health and provincial governors, while hospital emergency services in hospital emergency departments of EDs - from the funds of the National Health Fund.

As of January 1, 2023, emergency medical service teams are financed from the National Health Fund's resources, instead of - as before - from the state budget. The exception is the activity of air emergency medical service teams, which is financed in the form of a subjective subsidy from the state budget, from the part whose disposer is the minister in charge of health. (Article 48 of the Law on State Emergency Medical Services, Journal of Laws 2006, No. 191, item 1410).

Table 2.

Subsidy from the state budget for the implementation of the tasks of medical rescue teams in 2007-2023

Year	Subsidy (in thousands of PLN)	Dynamics
2007	1146480	100
2008	1468873	128,12
2009	1722492	117,27
2010	1726052	100,21
2011	1758496	101,88
2012	1823691	103,71
2013	1834497	100,59
2014	1837947	100,19
2015	1844347	100,35
2016	1868117	101,29
2017	1918441	102,69
2018	2035029	106,08
2019	2145931	105,45
2020	2386730	111,22
2021	2385734	99,96
2022	3130578	131,22
2023	0	0,00

Source: NFZ (2024).

Over the period 2007-2022, the subsidy from the state budget for the implementation of the tasks of medical rescue teams remained fairly stable (Table 2). In the financial plan of the National Health Fund for 2023, the value of revenues from the subsidy from the state budget for the implementation of the tasks of medical rescue teams was determined. Their amount was planned at 2,967,020 thousands of PLN. As a result of transferring the source of financing of tasks carried out by medical rescue teams from subsidies from the state budget to the National Health Fund and changes in the financial plan templates, the President of the Fund reduced the planned value of revenue from a subsidy from the state budget for the implementation of tasks of medical rescue teams by 2,967,020 thousands of PLN. Thus, the value of the received funds from the subsidy from the state budget for this purpose amounted to 0 of PLN. If the subsidy is compared with the costs, it can be seen that the subsidy in the analyzed years was insufficient to cover the costs of implementing the tasks of medical rescue teams.

Table 3.*Costs of carrying out the tasks of medical rescue teams from 2007 to 2023*

Year	Costs of performing tasks	Dynamics
2007	1146595	100
2008	1468761	128,10
2009	1722516	117,28
2010	1726042	100,20
2011	1758472	101,88
2012	1823691	103,71
2013	1834497	100,59
2014	1837947	100,19
2015	1844350	100,35
2016	1868118	101,29
2017	1918470	102,70
2018	2034616	106,05
2019	2146278	105,49
2020	2417824	112,65
2021	2449379	101,31
2022	3151477	128,66
2023	3767606	119,55

Source: NFZ (2024).

In the years 2007-2023, except for the years 2008, 2009, the pandemic year 2020, and the years 2022 and 2023 were rather stable (Table 3). In 2023, costs were planned at the amount of the original subsidy. However, due to changes in legislation and changes in the financial plan of the National Health Fund for 2023, the cost of carrying out the tasks of emergency medical teams was planned at 3,790,868 thousands of PLN, and executed at 3,767,606.18 thousands of PLN. These costs were realized at a lower level than planned by 23,261.82 thousands of PLN. However, they turned out to be higher than the costs incurred in 2022 by 616,128.71 thousands of PLN, or 19.55% (NFZ, 2023).

4. Conclusions

The Polish Emergency Medical Service system is currently undergoing an evolution towards the Anglo-American model. This is evidenced by the decreasing number of specialized teams, while the number of basic teams is increasing.

The transfer of financing from the state budget, to the National Health Fund is difficult to assess after such a short period of operation of the new financing model. Year after year, however, the system requires higher expenses. The financing mechanism for services can be a cause for concern, as the National Health Fund is an institution in which decisions on the purchase of services are limited by the financial plan. No greater commitments can be made than the amount of money that is guaranteed in the plan.

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References

1. Adnet, F., Lapostolle, F. (2004). International EMS systems: france. *Resuscitation*, 63(1), 7-9.
2. Al-Shaqsi, S. (2010). Models of international emergency medical service (EMS) systems. *Oman Medical Journal*, 25(4), 320.
3. Andres, J. (2022). *Wytyczne resuscytacji 2021*. Kraków: Polska Rada Resuscytacji.
4. Bélanger, V., Ruiz, A., Soriano, P. (2019). Recent optimization models and trends in location, relocation, and dispatching of emergency medical vehicles. *European Journal of Operational Research*, 272(1), 1-23.
5. Bem, A. (2013). Organizacja i finansowanie ratownictwa medycznego. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu*, 319, 158-167.
6. Chenaitia, H., Massa, H., Noel, C., Fournier, M., Verges, M., Emeric, S., ... Michelet, P. (2011). Paramedics in prehospital emergency medical systems across Europe. *International Paramedic Practice*, 1(1), 33-39.
7. Dick, W.F. (2003). Anglo-American vs. Franco-German emergency medical services system. *Prehospital and disaster medicine*, 18(1), 29-37.
8. Dijkink, S., Nederpelt, C.J., Krijnen, P., Velmahos, G.C., Schipper, I.B. (2017). Trauma systems around the world: a systematic overview. *Journal of trauma and acute care surgery*, 83(5), 917-925.
9. GUS (2021). *Pomoc doraźna i ratownictwo medyczne w 2020 r. Informacja sygnałna*.
10. GUS (2024). *Pomoc doraźna i ratownictwo medyczne w 2023 r. Informacja sygnałna*.
11. Konstytucja Rzeczypospolitej Polskiej, Dz.U. 1997, nr 78, poz. 483.
12. Kuehl, A. (Ed.) (2002). *Prehospital systems and medical oversight*. SAGE Publications.
13. LPR (Lotnicze Pogotowie Ratunkowe), <https://www.lpr.com.pl/pl/charakterystyka-zespolu-lotniczego-transportu-sanitarnego/>, 12.09.2024.
14. Makrides, T., Ross, L., Gosling, C., Acker, J., O'Meara, P. (2022). From stretcher bearer to practitioner: a brief narrative review of the history of the Anglo-American paramedic system. *Australasian Emergency Care*, 25(4), 347-353.
15. McConnell, K.J., Gray, D., Lindrooth, R.C. (2007). The financing of hospital-based emergency departments. *Journal of Health Care Finance*, 33(4), 31-52.

16. Miłowski, T., Mitura, K.M., Celiński, D., Perłowski, T., Jastrzębski, P., Zalewska-Szajda, B., Szajda, S.D. (2024). Emergency medical service through the centuries—the Polish perspective. *Medical Research Journal*, 9(1), 113-119.
17. NFZ (2024). *Roczne sprawozdanie z wykonania planu finansowego narodowego funduszu zdrowia na 2023 rok*.
18. Pozner, C.N., Zane, R., Nelson, S.J., Levine, M. (2004). International EMS systems: The United States: past, present, and future. *Resuscitation*, 60(3), 239-244.
19. Roessler, M., Zuzan, O. (2006). EMS systems in Germany. *Resuscitation*, 68(1), 45-49.
20. Spiteri, A. (2008). EMS systems in Malta. *Resuscitation*, 76(2), 165-167.
21. Ustawa z dnia 10 maja 2018 r. o zmianie ustawy o Państwowym Ratownictwie Medycznym oraz niektórych innych ustaw (Dz.U. 2018, poz. 1115).
22. Ustawa z dnia 22 listopada 2013 r. o systemie powiadamiania ratunkowego (Dz.U. z 2023 r., poz. 748).
23. Ustawa z dnia 25 lipca 2001 r. o Państwowym Ratownictwie Medycznym. Dz.U. 2001, nr 113, poz. 1207.
24. Ustawa z dnia 5 stycznia 2011 r. o kierujących pojazdami. Dz.U. 2011, nr 30, poz. 151.
25. Ustawa z dnia 8 września 2006 r. o Państwowym Ratownictwie Medycznym. Dz.U. 2006, nr 191, poz. 1410.
26. World Health Organization. Regional Office for Europe & European Union (2008). *Emergency medical services systems in the European Union: report of an assessment project co-ordinated by the World Health Organization*. Copenhagen: WHO Regional Office for Europe.
27. Zarządzenie nr 179/2022/DSM Prezesa Narodowego Funduszu Zdrowia z dnia 30 grudnia 2022 r. zmieniające zarządzenie w sprawie określenia warunków zawierania i realizacji umów w rodzaju ratownictwo medyczne.

MODERN MANAGEMENT SYSTEMS IN ENTERPRISES

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Purpose: The article aims to characterise integrated business management systems and demonstrate their usefulness for management.

Design/methodology/approach: The aim was pursued with a literature review, critical literature analysis, and expert judgement.

Findings: Having an integrated management system by an enterprise is increasingly becoming a condition for cooperation both on the domestic and foreign markets. The introduction of an integrated management system requires the involvement of all employees in increasing work safety and their greater involvement in performing daily duties. Having an integrated management system by the company increases the trust not only of customers in the company but also of employees.

Practical implications: The results suggest that integrated management systems may help achieve a competitive market advantage.

Social implications: Deploying an integrated management system empowers the enterprise to manage corporate social responsibility. Such efforts follow from meeting growing customer expectations.

Originality/value: The article's added value lies in uncovering the potential brought by deploying integrated management systems in an enterprise. The deployment may give the company a market advantage. The results of the analysis show that an integrated management system can simultaneously manage quality, environment, and OSH.

Keywords: integrated management system, ISO standard, system certification.

1. Introduction

Organisations can rise to the challenge of growing market competition by deploying and using modern management systems. Goal achievement determines whether an organisation is successful in the market. How it accomplishes its tasks can be judged by its effectiveness. Still, the effectiveness of the organisation as a whole is determined by management's activity, which is responsible for coordinating and guiding it.

In today's rapidly evolving world, where technologies, markets, and environmental complexity pose an increasing challenge for organisations, they can resort to advanced analytical tools (Bresciani et al., 2022; Forliano et al., 2022).

It takes both knowledge and the ability to use and manage it to improve how business is managed in diversified surroundings (Skrzypek, 2018). The management's interest in learning about and implementing integrated management systems may turn out to be a key to success.

The article aims to characterise integrated business management systems and demonstrate their usefulness for management. The methods employed to pursue the research objectives are a literature review, critical literature analysis, and expert judgment.

2. Integrated Management System

The literature does not offer a single definition of a management system. It first appeared as a management sciences term in the 1970s. A management system is a tried and tested structure for managing and continuously improving an organisation's productivity, policies, procedures, and processes. A management system has to have the following components (Senczyk, 2014):

- designed objective, the effect it is intended to achieve,
- operational resources, that is, all tangible and intangible assets for reaching the objective,
- processes to achieve the objective,
- inputs, data, guidelines, information, energy, materials, semi-finished products, components, etc.,
- outputs with which the designed objective is achieved.

A correctly completed process of improving a management system with proper management techniques and methods may contribute to numerous outcomes. These can be economic and financial benefits, such as increased profitability or income, better budget execution, cost reduction, improved cash flows, better ROI, better competitive advantage, sounder decision-making, customer retention, and increased customer loyalty. It can also lead to the optimal use of resources, boosted intellectual capital, greater sense of responsibility among employees, better effectiveness of the organisation's processes, enhanced supply chain, reduced delivery time, and elevated productivity, credibility, and resilience of the organisation (Skrzypek, 2016).

One of the fundamental characteristics of integrated management systems (IMSs) is their integration, which contributes to system cohesion, better organisations, and the potential for more usability. They bring together production and distribution processes and enable organisations to respond quickly to threats and opportunities (Pietras, 2017; after Rzewuski, 2002). Changes in organisations entail costs. Costs of developing and deploying an integrated management system include (Urbaniak, 2006):

- costs of employee training;
- costs of employees who draft and verify IMS procedures and instructions;
- costs of hardware and software;
- costs of drafting, implementing, and monitoring documentation;
- costs of internal audits and reviews;
- costs of pursuing objectives and tasks (preparation of plans and programmes and system monitoring by organisational units).

A certification audit fee is also a quantifiable cost of an IMS. Typically, large enterprises more readily appreciate the significant benefits of IMS deployment than small and medium enterprises. The high cost is the primary factor when deciding whether to deploy an IMS.

Benefits of an integrated management system include image, employee engagement and motivation, and greater market share, which may take some time to emerge (Górska, Lewandowski, 2002). The success of any management concept depends on the people: their knowledge, skills, attitudes, and commitment to the interests of the enterprise (Skrzypek, 2017).

An integrated management system can provide opportunities for continuous improvement of business effectiveness. Another important characteristic of a system is that it is continuously active as opposed to programmes. Management development is inherently linked to the continuous growth of processes in the enterprise. Enterprises first focused on quality in their business processes. Other needs arose over time, emerging from new expectations for environment protection, occupational safety, or information security (Rączka, 2008). Individual segments of the system can be deployed in parallel or consecutively. Experience suggests that the consecutive approach is better for avoiding mistakes thanks to experience and expertise. This makes the process faster and cheaper. The deployment should be divided into distinctive phases to facilitate inter-stage reviews and corrections. An integrated management system usually consists of hierarchical subsystems that are interdependent and interrelated. Business management systems come in two types: offline and online. Generally, offline systems use paper forms or simple tools in Excel, for example, as inputs and outputs. Online systems, on the other hand, are accessed via a web browser from any place (Senczyk, 2014). Integration of management systems usually involves systems defined in international, European, and national standards, such as ISO 9001, ISO 14001, or PN-N 18001.

An integrated management system is two or more collaborating and complementary subsystems in an organisation. These are usually quality, environment, or OHS management systems. Still, it is not enough to deploy each such system to expect improvement in management. Although previously perceived as completely disjoint, these domains started to entwine as the subsystems were deployed, and the need for their integration emerged.

An integrated management system can be based on any existing system, such as ISO, QMS (quality management system), or EMS (energy management system), that is suitable for the enterprise.

The need for integrated management systems emerges from the organisation's desire to more fully meet the public's needs and more effectively manage the enterprise (Senczyk, 2014). Every part of the system should be designed to adapt to the variable conditions of everyday operations and to make information transfer as fast as possible (Stawowy, 2018).

Deployment of ISO 9001:2000 is an important factor for arranging production processes (Węgrzyn, 2007). Integrated management systems involve a strategy for managing multiple systems in an enterprise while meeting customer needs and expectations.

3. System Certification

An integrated management system is founded on standards. An organisation with such a system may be certified for compliance with the standards. Each area has its specific standards: PN-EN ISO 9001:2009, PN-EN ISO 14001:2005/AC:2009, PN-N-18001:2004, and PN ISO/IEC 27001: 2007. They are guidelines the enterprise needs to follow to be certified.

PN-EN ISO 9001 sets requirements for a quality management system for enterprises that aim at demonstrating their capability of constantly delivering a compliant product that meets customer requirements. This standard can apply to various businesses regardless of their focus and size. It may be used by production, trade, and service entities.

Quality improvement efforts can be initiated when the enterprise is certified for compliance with ISO 9001: 2015. This standard has replaced the previous one, 9001:2008. Procedures in ISO 9001 have been streamlined, and the required documentation is minimal. ISO 9001 certification is the first step on the path to improved processes and quality control.

Benefits of a quality management system and certification (<https://www.udt.gov.pl/certyfikacja-systemow-zarzadzania/pn-en-iso-9001-2009-system-zarzadzania-jakoscia>):

- improved management and boosted effectiveness and efficiency of business processes;
- proper monitoring of the management system in the enterprise;
- availability of a tool for ensuring a high quality of products;
- improved customer confidence in product quality and safety;
- improved competitiveness in national and international markets;
- greater choice of procedures for EU directive conformity assessment;
- compliance with many tender procedure specifications;
- possible integration with other management systems.

An enterprise seeking to be ISO 9001 certified undergoes external audits by a certification body. These audits evaluate procedures, documentation, performance, and standard compliance. ISO 9001 certification requires a commitment to continuous improvement. The enterprise should monitor its results, hold regular management reviews, and analyse data and feedback to identify areas for improvement. Corrective action planning and implementation, as well as keeping the

quality management system up to date and effective, are critical for maintaining the ISO 9001 certificate (<https://ikmj.com/istotne-aspekty-zwiazane-z-certyfikacja-iso-9001/>).

Some EU state regulations require that businesses in certain industries be certified to participate in supply chains. In other sectors, such certificates contribute a significant competitive advantage. ISO 9001 standards can be used in any industry. The primary principle of management through quality articulated in the standards is to perceive the enterprise from the process perspective.

Regardless of certification, businesses with many management systems can gain a holistic picture of management activities in the organisation. Enterprises can be empowered to add significant value to their operations while stimulating the sustainable development of their procedures and processes (Rebelo et al., 2016).

4. Quality Management Systems

Deployment of an ISO 9001 quality management system takes time, effort, and commitment from all personnel. The process usually involves identifying and recording processes, developing procedures, monitoring performance, holding internal audits, managing the quality system documentation, and conducting risk analysis and corrective actions (Fig. 1) (<https://ikmj.com/istotne-aspekty-zwiazane-z-certyfikacja-iso-9001/>).

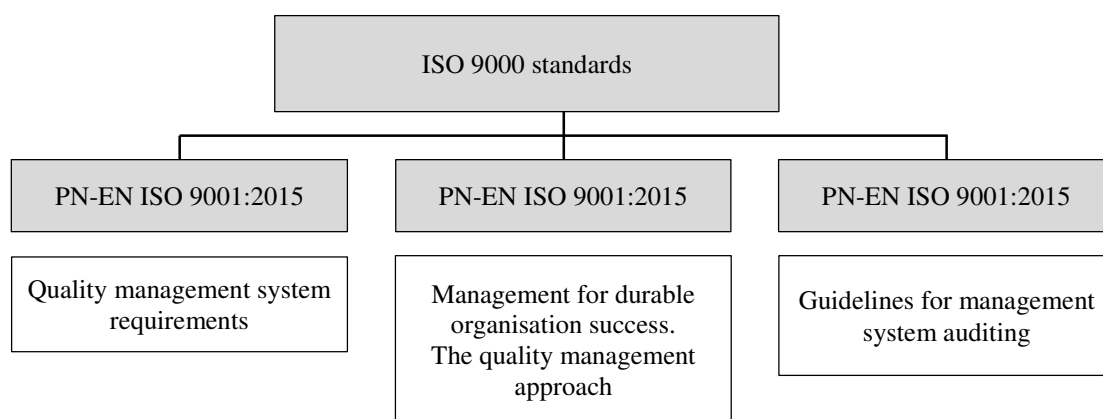


Figure 1. Summary of ISO 9000 standards.

Source: Nowak, Pawluk, 2016, pp. 45-52.

ISO 9001:2015 requires that an enterprise with a quality management system define its scope. It should be kept as documented information, considered in the business context, include the requirements of significant stakeholders, and define the products or services the system covers. The quality management system should also be easily available. The quality management system scope includes such items as the Hallmarking Act compliance monitoring, internal supervision, keeping a register of maker's marks, procedures for nonconformities and complaints,

and coordination and supervision over the activities of branch divisions regarding testing and hallmarking precious metal products (Motyka, 2019). ISO 9004 provides guidelines for permanent business success. Its objective is to increase the organisation's credibility and warrant its long-term, permanent success. It helps enterprises identify and balance the needs and expectations of their customers with the needs and expectations of other stakeholders in a complex and ever-evolving business environment. ISO 9004 is not designed strictly for certification. It contains an improved self-assessment tool to help enterprises evaluate the maturity of various components of their systems and identify and prioritise potential areas for improvement. It is useful for moving to the next level beyond ISO 9001. It concerns such issues as adjusting and implementing strategies, policies, and goals as part of a broader vision, mission, values, and organisational culture (<https://www.iso.org/news/Ref2187.htm>). ISO 9004's description of process management offers a very useful complement to the process approach proposed in ISO 9001. It gives a better understanding of process management and introduces new elements compared to ISO 9001, such as identifying stakeholders' needs and developing links between process management and strategic management. Still, similarly to the description in ISO 9001, the one in ISO 9004 is superficial and does not provide detailed guidelines for specific actions to be taken in the enterprise (Brzozowski, Rogala, 2017).

An enterprise with a management system needs to conduct regular audits to make sure the system is effective. ISO 19011 is useful in this regard. It offers recommendations intended to help businesses develop an audit programme to facilitate compliance with the requirements of various ISO standards. Guidelines in ISO standards are the foundations for internal audits that the enterprise may need to assess its suppliers and for third-party audits necessary for certification.

An ISO 9001 certificate is proof of high quality standards. It improves customer confidence and gives a competitive advantage. Every enterprise is different, so an ISO 9001 certificate brings various benefits depending on the business context and goals.

5. Environmental Management Systems

The goal of environmental management in business is to minimise the impact on natural resources, satisfy customer expectations, and elevate brand image. An environmental management system involves the executives and other employees. The system is evaluated at least once a year.

The key ISO 14000 standards are those for environmental management systems (ISO 14001 and ISO 14004). An environmental management system is a management tool empowering the enterprise to identify and monitor the environmental impact of its activities, products, and services, refine the environmental effects of its business, and implement a systemic approach to defining, achieving, and verifying environmental goals. The series of ISO 14000 standards

includes standards for environmental management systems, environmental labelling, environmental impact assessment, life cycle evaluation, product design and development with the environment in mind, environmental communication, greenhouse gas and climate change issues, water and carbon footprint, and environmental costs (<https://wiedza.pkn.pl/web/wiedza-normalizacyjna/srodowisko>). ISO 14001 specifies requirements for building environmental management systems in different enterprises. The environmental management system model is founded on the principle of continuous improvement. The primary purpose of the system is defined as support for activities related to environment protection and pollution control and prevention. The idea behind ISO 14001 is to improve environment protection activities by identifying threats, estimating risks, and encouraging enterprises to be environmentally compliant (Jagodzińska, 2019). The following revisions in ISO 14001 have been emphasised (Introduction, 2015):

- environmental management as a component of strategic operational axes in organisations;
- increased role of commitment and leadership from managers;
- requirements for proactive initiatives for environment protection, such as the use of renewable resources and mitigation of climate change exacerbation;
- need for life-cycle-based thinking to consider environmental aspects from product design to end-of-life stages;
- requirements for a stakeholder-oriented communication strategy (Jedynak, 2019).

ISO 14001 focuses on natural environment protection. An environment management system concentrates on reducing waste, methods and ways for waste management, pollution prevention, reducing consumption of natural resources, and cutting down emissions in the transport industry (Jagodzińska, 2019). Note that ISO 14001 is part of a large ISO 14000 series. In addition to the superior ISO 14001, the series includes such standards as (Jedynak, 2019):

- ISO 14004, which provides guidelines for developing, deploying, maintaining, and improving an environmental management system and coordinating it with other management systems;
- ISO 14006 for organisations that already have an environmental management system but need to integrate it with eco-design activities;
- ISO 14064-1 with regulations and requirements for greenhouse gas emissions quantification and reporting.

Advantages of deploying ISO 1400 (<https://adees.com.pl/norma-iso-14001/>):

- improved environmental awareness of personnel;
- improved image of an environmentally-friendly business;
- compliance with environmental regulations;
- curbed liquid and solid waste.

6. Occupational Safety and Health Management System

The International Organization for Standardization (ISO) published the first global harmonised standard for occupational safety and health management systems, ISO 45001:2018, on 12 March 2018. The new ISO 45001:2018 replaced former standards containing OSH requirements: BS OHSAS 18001:2007 and PN- N 18001:2004 (<https://www.iso.org.pl/artykuly-i-informacje-dotyczace-systemow-zarzadzania/artykul-iso-450012018-nowa-norma-dotyczaca-zarzadzania-bhp-2019-01-25/>). ISO 45001 is applicable to all organisations, regardless of size, industry, and nature of business. It is designed to be integrated into an organisation's existing management processes and follows the same high-level structure as other ISO management system standards, such as ISO 9001 (quality management) and ISO 14001 (environmental management) (ISO 45001). ISO 45001:2018 is the first standard on occupational safety and health issued by the International Organization for Standardization. It is founded on several key principles: the PDCA cycle: plan, do, check, and act and risk and opportunity management. The standard focuses on managing risks and opportunities emerging from the OSH management system. The new ISO 45001 increases the involvement of executives in OSH and integration with other management systems. The sections are arranged according to the HLS principle (High-Level Structure) used in ISO 14001:2015 and ISO 9001:2015 for easier integration with other management systems (Bartczak, 2023).

According to the International Labour Organization, almost 3 million people die every year of workplace accidents and conditions, with 330 thousand attributable to accidents. It is nearly 5% more than in the 2015 report (<https://www.bankier.pl/wiadomosc/Smiertelne-zniwo-wypadkow-przy-pracy-Przerazajace-miedzynarodowe-dane-8653630.html>). Accidents at work are on the rise in Poland as well. According to preliminary Statistic Poland's data for 2023, the number of workplace casualties in Poland and the accident rate grew compared to 2022. The number of people reported as casualties of accidents at work in 2023 was 68,663, which is 3.1% more than in 2022. The ratio of casualties per 1000 employees also grew from 4.66 to 4.90 (Statistics Poland, 2024). Therefore, it is important to implement standards that improve occupational safety. ISO 45001:2018 reduces workplace risks by providing better and safer work conditions.

7. Conclusions

All systems need regular management reviews and defining goals in line with the particular system. Implemented and certified integrated management systems improve the quality of work at the enterprise, leading to fewer complaints and higher levels of personnel safety. This contributes to the market advantage. Integrated management systems have become the prerequisite for business partnerships at home and internationally. Better quality (expected by

buyers) increases profits through reduced internal costs. Deployment of an integrated management system contributes to ongoing improvement of environmental efforts, leading to a better state of the environment. Integrated management systems also safeguard enterprises against fines through compliance. Deployment of an integrated management system necessitates the engagement of all employees in occupational safety efforts and everyday duties. This boosts confidentiality among both customers and employees.

References

1. Bartczak, P. (2018). Adaptacja polskiego systemu ISO 45001. *Przedsiębiorczość i Zarządzanie*, 2, 53-63.
2. Bresciani, S., Rehman, S.U., Alam, G. M., Ashfaq, K., Usman, M. (2022). Environmental MCS package, perceived environmental uncertainty and green performance: in green dynamic capabilities and investment in environmental management perspectives. *Review of International Business and Strategy*, 33(1), 105-126.
3. Brzozowski, T., Rogala, P. (2017). Podejście procesowe według norm ISO serii 9000 – istota i ewolucja. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu*, nr 470, pp. 19-28.
4. Duhigg, Ch. (2016). *Mądrzej, szybciej, lepiej. Sekret efektywności*. Warszawa: PWN.
5. Forliano, C., Ferraris, A., Bivona, E., Couturier, J. (2022). Pouring new wine into old bottles: A dynamic perspective of the interplay among environmental dynamism, capabilities development, and performance. *Journal of Business Research*, 142, 448-463.
6. Górka, E., Lewandowski, J. (2002). *Podstawy zarządzania i kształtowania środowiska pracy*. Warszawa: Oficyna Wydawnicza Politechniki Warszawskiej.
7. GUS (2024). <https://stat.gov.pl/obszary-tematyczne/rynek-pracy/warunki-pracy-wypadki-przy-pracy/wypadki-przy-pracy-w-2023-r-dane-wstepne,3,54.html>
8. <https://adees.com.pl/norma-iso-14001/>, 25.09.2024.
9. <https://ikmj.com/istotne-aspekty-zwiazane-z-certyfikacja-iso-9001/>, 1.08.2024.
10. <https://wiedza.pkn.pl/web/wiedza-normalizacyjna/srodowisko>, 28.09.2024.
11. <https://www.bankier.pl/wiadomosc/Smiertelne-zniwo-wypadkow-przy-pracy-Przerazajace-miedzynarodowe-dane-8653630.html>, 1.10.2024.
12. <https://www.iso.org.pl/artykuly-i-informacje-dotyczace-systemow-zarzadzania/artykul-iso-450012018-nowa-norma-dotyczaca-zarzadzania-bhp-2019-01-25/>, 26.09.2024.
13. <https://www.iso.org/news/Ref2187.htm>, 25.09.2024.
14. <https://www.udt.gov.pl/certyfikacja-systemow-zarzadzania/pn-en-iso-9001-2009-system-zarzadzania-jakoscia>, 1.08.2024.
15. Introduction to ISO 14001:2015 (2015). Geneva: International Organization for Standardization.

16. Jagodzińska, N. (2019). Wymagania standardu zarządzania środowiskowego ISO 14001 i spodziewane efekty jego wdrażania w przedsiębiorstwach transportowych. *Autobusy*, 6, pp. 71-74.
17. Jedynak, P. (2017). Znormalizowane systemy zarządzania a ryzyko działalności organizacji. Kraków: Wydawnictwo Uniwersytetu Jagiellońskiego.
18. Motyka, J. (2019). System Zarządzania Jakością w OUP w Warszawie. *Metrologia i Probiernictwo – Biuletyn Głównego Urzędu Miar*, 1(22), pp. 66-70.
19. Nowak, A., Pawluk, A. (2016). Zintegrowany System Zarządzania w odniesieniu do zrównoważonego rozwoju w przemyśle wydobywczym węgla kamiennego. *Journal of the Polish Mineral Engineering Society*, pp. 45-52.
20. Pietras, E. (2017). Istota zintegrowanego systemu zarządzania klasy ERP, za M. Rzewuski, Ewolucja Systemów zarządzania - ERP II – Nowy stary gatunek. *PC Kurier*, 20/2002.
21. Rączka, M. (2008). Systemy zarządzania jako element rozwoju przedsiębiorstwa. *Zeszyty Naukowe Politechniki Rzeszowskiej. Zarządzanie i Marketing*, pp. 249-256.
22. Rebelo, M.F., Santos, G., Silva, R. (2016). Integration of management systems: Towards a sustained success and development of organizations. *Journal of Cleaner Production*, 127, 96-111.
23. Scott, D. (2015). *Nie przeszkadzaj klientowi w zakupach*. Warszawa: PWN.
24. Senczyk, D. (2014). Zintegrowane systemy zarządzania w przedsiębiorstwie na wybranych przykładach. *Przegląd Naukowo-Metodyczny, Edukacja dla bezpieczeństwa*, 1(22). Poznań, pp. 153-163.
25. Skrzypek, E. (ed.) (2018). *Zarządzanie organizacją w warunkach różnorodności*. Lublin: Katedra Zarządzania Jakością i Wiedzą, UMCS.
26. Skrzypek, E. (2018a). *Nowoczesne trendy w zarządzaniu a doskonalenie zarządzania*. Lublin: Wydawca Katedra Zarządzania i Marketingu, Wydział Agrobioinżynierii, Uniwersytet Przyrodniczy w Lublinie.
27. Skrzypek, E. (2016). Paradygmaty zarządzania wiedzą w warunkach zmian otoczenia. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu*, no. 419.
28. Skrzypek, E. (2017). Knowledge as the basis of a new in management. In: E. Skrzypek (ed.), *Quality of management*. Lublin: Department Quality and Knowledge Management, Faculty of Economics, University of Maria Curie-Skłodowska.
29. Stawowy, A. (2018). System zarządzania a elastyczność organizacji – analiza literaturowa i konceptualizacja. *Zeszyty Naukowe Politechniki Śląskiej, Seria: Organizacja i Zarządzanie* z. 127, pp. 243-254.
30. Urbaniak, M. (2006). Korzyści wynikające z wdrożenia systemów zarządzania. *Problemy Jakości*, no. 7.
31. Węgrzyn, B. (2007). Zintegrowany System Zarządzania etapem kształtowania w przedsiębiorstwie Zarządzania przez Jakość (TQM). *Przegląd Organizacji*, No. 6(809), pp. 37-40.

BALANCING EFFICIENCY AND FLEXIBILITY – A SIMULATION OF LINE CONFIGURATIONS

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Purpose: The purpose of the study is to examine the impact of production line configurations on operational efficiency using simulation tools. Analyzing various scenarios with a variable number of production lines allows for an assessment of how infrastructure modifications affect system performance, resource management, and operational flexibility.

Design/methodology/approach: The study was conducted using FlexSim software, which enables the modeling and analysis of production processes. Key steps included: collecting operational data, developing a simulation model, validating the model, and analyzing the results for three configurations: one, two, and three production lines. Model validation was performed by comparing simulation results with real-world operational data.

Findings: The findings indicate that a single production line ensures high operational efficiency (around 98%), but its rigidity limits adaptability under changing conditions. Adding a second production line results in a moderate decrease in efficiency (approximately 1.2%), while significantly enhancing flexibility and resource management capabilities. Three production lines offer the highest flexibility; however, efficiency drops to approximately 80%, which may cause challenges related to underutilized resources and increased operational costs. The optimal solution, balancing flexibility and efficiency, is the addition of a second production line. Adding a third line may only be justified under conditions of significant demand growth.

Research limitations/implications: The study's limitations stem from the simplifications in the model, such as the assumption of constant production parameters and the exclusion of market variability. Future research should consider dynamic market conditions and a more comprehensive cost analysis.

Originality/value: The study introduces an innovative approach by applying computer simulation to evaluate the efficiency of different production line configurations. The insights provided in the article are valuable for production engineers and managers, assisting them in making informed decisions about optimizing production systems.

Keywords: Computer simulation, Production optimization, System flexibility, Resource management, Production engineering.

Category of the paper: Research paper and case study.

1. Introduction

The modern manufacturing industry faces the challenge of continuously optimizing processes to enhance operational efficiency and the flexibility of production systems. The use of advanced simulation tools, such as FlexSim, enables modeling and analysis of various production line configurations, facilitating the identification of potential improvements and better resource management (Dubaj, 2023).

Research indicates that production process simulation allows for verifying system performance before implementation or during modifications, such as expanding the product portfolio or changing production volumes (Asseco CEIT, 2024). This approach makes it possible to identify bottlenecks and optimize material flow and resource allocation, ultimately leading to increased operational efficiency (DS-Technic, 2024).

The objective of this article is to evaluate the impact of different production line configurations on operational efficiency using advanced simulation tools. The analysis encompasses scenarios with one, two, and three production lines, enabling an assessment of how infrastructure changes influence system performance, resource management, and operational flexibility. The application of computer simulations provides a detailed understanding of production processes and supports informed strategic decision-making in the optimization of production systems.

2. Theoretical background of the study

Computer simulation plays a crucial role in production management, enabling the analysis and optimization of processes without interfering with the actual system. It allows for the identification of bottlenecks, optimization of material flow, and reduction of operational costs through more effective resource utilization (Dubaj, 2023). Modern manufacturing enterprises must operate in a dynamically changing market environment, which requires flexible and efficient process management (Borshchev, Filippov, 2004). Research indicates that the use of simulation can increase production system efficiency by 10-20%, making it a key element of management strategies (Greasley, 2017).

Various tools supporting process simulation are widely used in the manufacturing industry. The most commonly utilized include FlexSim, AnyLogic, and Arena Simulation. Each of these tools offers unique features that facilitate the modeling of complex production processes and the real-time analysis of performance metrics (Borshchev, 2013; Greasley, 2017).

FlexSim is one of the most versatile tools for production simulation. It offers features such as dynamic modeling, "what-if" scenario analysis, and resource optimization (Dubaj, 2023). Its application in the food industry has demonstrated a 15% reduction in production cycle time and improved resource management (Dubaj, 2023).

AnyLogic stands out for its ability to integrate logistics and multi-aspect simulations, making it a valuable tool for analyzing complex supply chains (Borshchev, Filippov, 2004). On the other hand, Arena Simulation is widely used in the automotive industry, where it enables precise analysis of material flows and production capacity (Greasley, 2017).

Computer simulation is widely used in scientific research as a tool for analyzing the efficiency of production processes and forecasting outcomes in complex systems (Borshchev, 2013). Studies by Dubaj (2023) indicate that the application of FlexSim in the electronics and food industries has delivered significant benefits, including a 20% reduction in downtime. Similar results were achieved in research by Greasley (2017), where simulations facilitated the identification of critical points in production systems, contributing to overall performance improvements (Cigolini et al., 2014).

The use of simulation tools such as FlexSim and Arena also enables integration with ERP systems, enhancing forecasting precision and supporting strategic decision-making (Borshchev, 2013). The role of simulation in the design and operation of production systems is expected to grow significantly in the future (Sobottka et al., 2017).

The manufacturing sector, as a critical component of the global economy, is becoming increasingly competitive, necessitating the adoption of modern tools to support its development (Daaboul et al., 2014). Faced with growing process complexity and the need for flexible responses to changing market conditions, enterprises are challenged to implement more advanced and efficient optimization techniques (Karwat et al., 2022).

Computer simulation, recognized as one of the most effective tools in this domain, enables better understanding and management of complex production systems (Prajapat, Tiwari, 2017). The growing significance of simulation is driven by the need to reduce operational costs, enhance efficiency, and minimize risks associated with implementing new production strategies (Kusiak, 2020).

Simultaneously, increasing digitalization and the integration of technologies such as artificial intelligence and machine learning are opening new opportunities for simulation in the industrial sector (Chen et al., 2022). Automation of processes, "what-if" modeling, and future scenario forecasting allow companies to enhance flexibility and adapt to dynamic changes in the economic environment. As a result, simulation is evolving from being merely an operational tool to becoming a strategic instrument that supports the long-term development of organizations (Lidberg et al., 2020).

3. Methods

The aim of the study was to conduct a detailed analysis of the impact of various production line configurations on key performance indicators (KPIs) and the flexibility of the production system. The use of computer simulation enabled accurate replication of real-world production processes, allowing for the testing of alternative scenarios without disrupting ongoing operational activities.

FlexSim was selected as the simulation tool due to its advanced functionalities, which were ideally suited to the needs of the study. In this case, FlexSim enabled:

- 3D Process Modeling – Accurate representation of the physical structure of the production system, including the layout of production lines, machine placement, and material flows.
- 3D Visualization – Tracking material flow and identifying potential bottlenecks through real-time visual simulations.
- Dynamic Real-Time Simulations – Analysis of material flows and resource utilization in real time, enabling the monitoring of system efficiency changes based on the number of production lines.
- "What-If" Scenario Analysis – Creation and comparison of various production system configurations, crucial for evaluating their impact on operational efficiency and flexibility. Testing different scenarios allowed for the identification of the optimal configuration.
- Generation of Operational Efficiency Indicators – Automatic generation of key performance indicators (KPIs), such as lead time, resource utilization, and idle resources, providing measurable insights into system performance.
- Reporting and Visualization of Results – The tool enabled the generation of detailed reports, including heat maps of machine utilization, material flow diagrams, and KPI charts. These reports were essential for interpreting results and presenting differences among the analyzed scenarios.

The research process was planned in several stages, each of which was crucial for achieving reliable results:

- Data Collection and Preparation – At the initial stage, detailed operational data on production processes were gathered. This included cycle times, production line structures, machine availability, and production capacities. The data were formatted appropriately for input into FlexSim.
- Development of the Simulation Model – The model was built within the FlexSim environment, replicating production processes in a virtual form. It included detailed decision variables such as the number of production lines, material flows, and resource allocation.

- **Model Validation** – To ensure the simulation model accurately reflected real-world operations, validation was performed. Simulation results were compared with historical operational data, confirming the model's alignment with reality.
- **Scenario Simulation** – Simulations were conducted for three scenarios, each analyzed based on key performance indicators and their impact on system flexibility: one production line (baseline scenario), two production lines (moderate flexibility), three production lines (maximum flexibility, potential efficiency challenges).

4. Results

The company analyzed specializes in the production of metal components with precise technical specifications, utilized across various industrial sectors. In a highly volatile market environment and amidst increasing expectations for quality and efficiency, optimizing the production system is of critical importance. To accurately replicate operational processes, a simulation model was developed based on a detailed layout of the production line. This section presents the results of the analysis conducted under three scenarios of system configuration.

To enable a realistic yet transparent analysis, the following key assumptions were adopted:

1. **Operational Parameter Stability** – It was assumed that operation cycle times, machine efficiency, and resource availability remain constant, reflecting average values derived from historical data.
2. **No Demand Variability** – The simulation model focused on optimizing the current production configuration, excluding the impact of dynamic changes in product demand.
3. **Machine Performance** – All machines were assumed to operate at maximum technical efficiency, with downtime occurring only due to failures or maintenance requirements, which were incorporated into the model parameters.

Model The simulation model was developed based on a detailed layout of the production line (Figure 1). The layout accounted for the placement of key production infrastructure elements, including:

- **Production Machines and Equipment** – The placement of machines along the production line was accurately modeled to reflect actual material flows and the operational characteristics of the system.
- **Storage Buffers** – The model included the location and capacity of buffers, enabling an analysis of interdependencies between production stages and identification of potential bottlenecks.
- **Quality Control Points** – Quality control checkpoints were defined on the factory floor layout, playing a critical role in maintaining production standards.

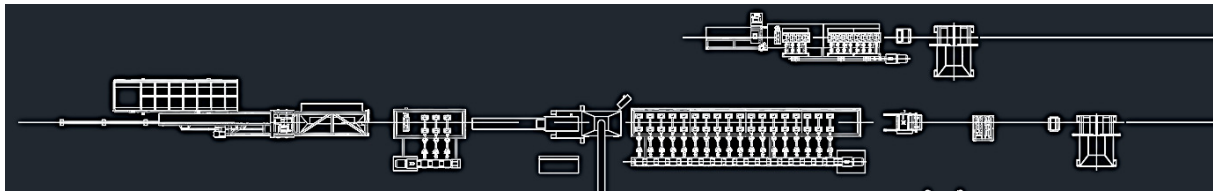


Figure 1. Production line layout.

The simulation based on the layout enabled realistic modeling of material flows, queues, and operational cycles. This facilitated a detailed analysis of the impact of changes in production line configurations on key operational performance indicators.

Subsequently, using the production line layout, a detailed resource flow process was modeled in FlexSim software. The Process Flow illustrates all key stages of the production process, including resource generation, transport, processing, and quality control (Figure 2). Additionally, each block depicted in the diagram was thoroughly discussed, considering its role in the model and the key parameters used in the simulation.

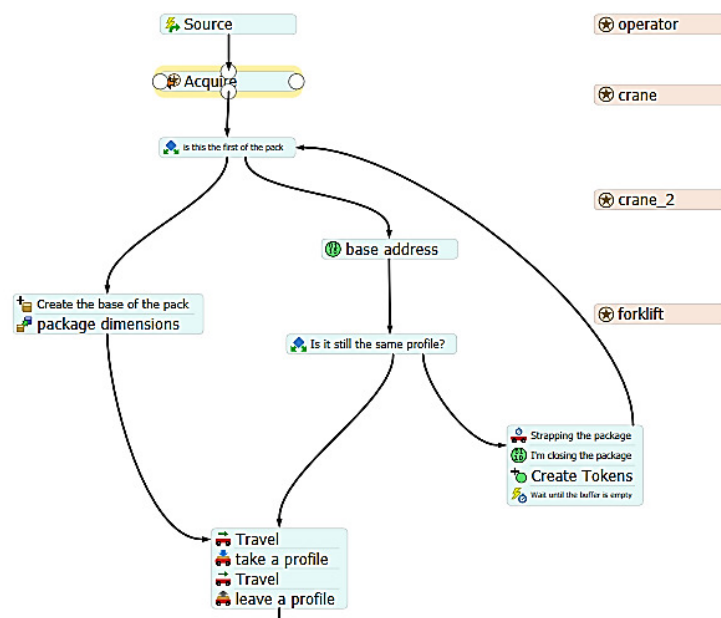


Figure 2. Production process – block diagram.

- **Source block (resource generation)** – This is the starting point of the process, responsible for introducing resources into the production system. At this stage, units representing input materials are generated. The block's parameters were configured to reflect real operational conditions. The number of generated units corresponds to the production batch size. A fixed resource introduction time was set to simulate a consistent material flow into the process.
- **Acquire block (resource allocation)** – This block handles the assignment of resources to operators or machines required for processing. At this stage, resources are allocated to the appropriate infrastructure elements. The system automatically checks the availability of the required resources. If the resources are available, they are assigned; if not, the process waits for resources to be released.

- Create the base of the pack block – This block is responsible for preparing unit packages, which serve as the primary transport units within the system. The block parameters included package dimensions and the maximum number of units that can be placed in a single package. At this stage, resources are grouped into sets, which are then passed to subsequent stages of the process.
- Base address block – This block performs a control function. At this stage, the system verifies whether the processed resources match the product defined at the beginning of the process. If the resource aligns with the specified profile, it continues in the process; otherwise, it is directed to an alternative path. This stage prevents the mixing of different types of materials, which is crucial for maintaining production quality.
- Travel block (resource transport) – Simulates the transportation of resources between successive stages of the production process. It accounts for various means of transport, such as operators, forklifts, and cranes. The block parameters included transport time and the availability of transportation resources.
- Is it still the same profile? block (product profile control) – Serves a control function by checking whether the processed resources still align with the declared profile. If the material profile changes during the process, resources are redirected to an alternative area. This mechanism prevents errors in further processing.
- Create tokens block – Generates tokens that act as indicators of operation progress within the system. These tokens represent the completion of key process stages, such as packaging or redirection. They allow for precise tracking of the status of each unit in the system.
- Auxiliary machines and operators – Their availability was included as a constraint in the model, enabling a realistic analysis of flow efficiency.

The model allowed for realistic replication of actual production operations, identification of potential bottlenecks, and evaluation of system efficiency under various operational scenarios. Based on the layout, it was also possible to configure parameters for each block, significantly enhancing the accuracy and value of the analysis.

As part of the study, simulations were conducted using the Experimenter module in FlexSim software, considering full utilization of the existing production line and the potential acquisition of one or two additional lines. The goal of the simulation was to determine the potential benefits and operational efficiency improvements resulting from the implementation of new production lines. This analysis enabled an assessment of the impact of new configurations on system performance.

For the study, three scenarios were defined:

- Scenario with one production line – The baseline system configuration, representing the current state of resource utilization.

- Scenario with two production lines – An extended configuration that includes the addition of one additional production line.
- Scenario with three production lines – The maximum system expansion, incorporating two additional production lines.

Each scenario was thoroughly analyzed using Performance Measure Tables, enabling precise determination of key indicators, such as:

- Production line efficiency – Measuring the utilization rate of available resources.
- Operator efficiency – Reflecting the workload and productivity level of operators.
- Average content of the Profile Packaging Line – Indicating the system's capacity to manage material flow.

To ensure the statistical reliability of the results, 500 replications were performed for each scenario. Setting this number of repetitions allowed for accounting for variability in production processes, eliminating the impact of random events on the final simulation outcomes, and obtaining more precise and reliable data that can serve as a basis for decisions regarding system expansion.

As part of the simulation, the impact of the number of production lines on key operational efficiency indicators and the system's adaptive capacity was examined. The analysis was conducted for three scenarios: one, two, and three production lines. The results are presented in the form of charts illustrating the average content of the packaging line (Figure 3), production line efficiency (Figure 4), and operator efficiency (Figure 5) in each of the considered scenarios.

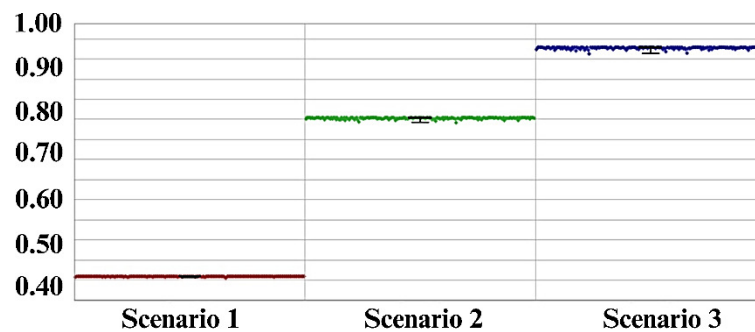


Figure 3. Analysis of the average content of the packaging line.

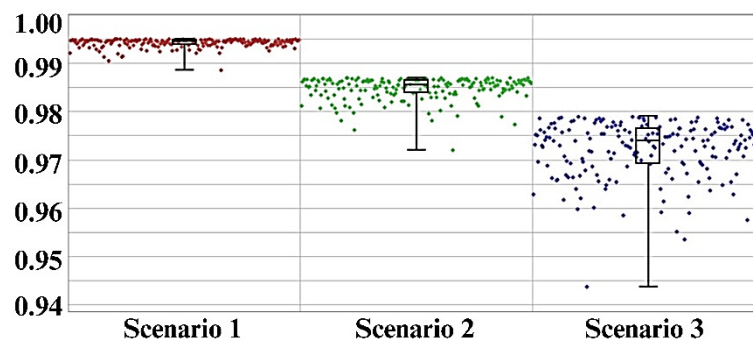


Figure 4. Analysis of production line efficiency.



Figure 5. Analysis of operator efficiency.

Average Content of the Packaging Line (Figure 3):

- Scenario 1 – An average content of approximately 0.4 indicates limited flow management capabilities with a single production line.
- Scenario 2 – The value increases to approximately 0.75, reflecting more efficient resource utilization with two production lines.
- Scenario 3 – A maximum value of 0.95 indicates the highest flow management capabilities, though with a potential risk of excessive idle resources.

Production Line Efficiency (Figure 4):

- Scenario 1 – An efficiency level of 1.0 (100%) indicates maximum utilization of a single production line.
- Scenario 2 – A decrease to approximately 0.98 shows that distributing work across two lines reduces the intensity of utilization for each line but increases system flexibility.
- Scenario 3 – Efficiency drops to approximately 0.95, suggesting underutilization of the full capacity of three production lines.

Operator Efficiency (Figure 5):

- Scenario 1 – Efficiency is approximately 0.2, indicating insufficient engagement of operators with a single production line.
- Scenario 2 – An increase to 0.45 reflects better utilization of operators in the two-line configuration.
- Scenario 3 – A value of approximately 0.52 indicates full operator engagement with three lines, though this requires more coordinated workforce management.

Based on the analysis, it was determined that the optimal solution for the studied system is the addition of one additional production line (the two-line scenario). This configuration achieves a balance between operational efficiency and system flexibility, ensuring the ability to handle higher demand while maintaining a high level of productivity. The introduction of a third line may only be justified in the case of a significant increase in demand or a reduction in the risk associated with resource underutilization.

To gain a more precise understanding of the efficiency differences between the analyzed scenarios, a detailed statistical analysis was conducted. The results are presented in Table 1, which highlights the differences in production efficiency between Scenario 1 and Scenarios 2 and 3, along with 95% confidence intervals.

Table 1.*Statistical Analysis of Differences in Production Line Efficiency Between Scenarios*

j	Line 1 i = Scenario 1 $\mu_j - \mu_i$ (95% Confidence Interval)	Statistically Significant
Scenario 1	-	-
Scenario 2	-0.009602 ± 0.000263	Yes
Scenario 3	-0.189022 ± 0.000220	Yes

The difference between Scenario 1 and Scenario 2 is -0.009602 ± 0.000263 , indicating that the efficiency of the production line in Scenario 2 is slightly lower than in Scenario 1. Despite the small difference, the analysis shows that the result is statistically significant, confirming the impact of adding a second line on system load.

The difference between Scenario 1 and Scenario 3 is -0.189022 ± 0.000220 , which indicates a significant decrease in efficiency when the system is expanded with a third production line. This result is also statistically significant, confirming that an additional line leads to an excess of unused resources.

Both Scenarios 2 and 3 show statistically significant differences, indicating that changes in the number of production lines have a measurable impact on system efficiency, which must be considered when making decisions about production expansion. The statistical analysis confirms that the introduction of a second production line (Scenario 2) causes a slight decrease in efficiency compared to the baseline scenario. However, the difference is small enough that the benefits of increased system flexibility may offset it. On the other hand, the introduction of a third line (Scenario 3) results in a substantial drop in operational efficiency, suggesting that the decision to add a third line should only be made in the context of a forecasted significant increase in demand.

5. Discussion

The aim of the study was to analyze the impact of various production line configurations on operational efficiency and system flexibility using advanced simulation tools. The results provide valuable insights into the trade-offs between efficiency, resource utilization, and the system's adaptability. By simulating three different scenarios—one, two, and three production lines—it was possible to quantitatively assess operational performance under different conditions and identify optimal configurations.

The findings clearly indicate that increasing the number of production lines improves system flexibility, but at the expense of operational efficiency. The scenarios with two and three lines allowed for better resource allocation and shorter order fulfillment times under increased

demand conditions. However, the lower resource utilization in these scenarios highlights the risk of underutilized production capacity and increased operational costs. The scenario with two production lines proved to be the most balanced solution, providing high efficiency (approximately 98%) while increasing system flexibility. This configuration helps reduce bottlenecks observed with one line while avoiding the resource surplus issues seen with three lines. Operator efficiency significantly improved with the addition of more production lines, reaching its highest value in the three-line scenario. This increase resulted from better workload distribution and reduced operator downtime. However, such a rise in system complexity requires more advanced workforce management and investment in training.

The results are consistent with previous research on the optimization of production systems, which emphasize the importance of balancing efficiency and flexibility (Mandolla et al., 2022). Previous studies have shown that increasing production capacity reduces the risk of system overload but introduces challenges such as underutilized resources and higher fixed costs (Lee, 2023). In this study, the application of FlexSim software confirmed its usefulness as a tool for analyzing these complex trade-offs, similar to findings in other studies on production system expansion.

The findings of this study provide specific recommendations for manufacturing enterprises planning production system expansion. Decision-makers should carefully evaluate the trade-offs between flexibility and efficiency to select the optimal number of production lines based on projected demand and budget constraints. The study highlights the importance of dynamic resource management, which enables adaptation to fluctuating demand. Tools like FlexSim allow for testing various configurations without the risk of losses in real production environments. The expansion of production lines necessitates attention to workforce management. Appropriate training and optimization of work schedules can increase operator efficiency while minimizing costs associated with overstaffing.

6. Summary

The study conducted within this article provides valuable insights into the optimization of production systems using simulation tools. The analysis of three scenarios—one, two, and three production lines—enabled an understanding of the key relationships between operational efficiency and system flexibility. The results clearly indicate that increasing the number of production lines improves the system's adaptive capacity but leads to reduced efficiency in cases of resource surplus.

The most balanced solution was the introduction of two production lines, which reduced bottlenecks and increased operational flexibility while maintaining high efficiency at approximately 98%. Expanding the system to three production lines offered maximum

flexibility but involved the risk of underutilized resources and a reduction in efficiency to 95%. These findings suggest that decisions regarding the expansion of production systems should consider projected demand and potential operational costs associated with maintaining unused resources.

The application of simulation tools, such as FlexSim, proved highly valuable in evaluating various configurations of production systems. By realistically replicating processes and enabling the analysis of different scenarios, this tool allows enterprises to make data-driven decisions, minimizing the risks associated with actual changes in production processes.

The study also highlights the importance of operator management in expanded production systems. Optimal employee utilization is critical to the effective functioning of the system, and increasing the number of production lines requires advanced schedule planning and appropriate training.

The limitations of the study, such as the assumption of constant production parameters and the exclusion of cost analysis, point to directions for future research. Introducing dynamic parameters, such as demand variability or cost analysis, would provide a more comprehensive view of the impacts of system expansion. Additionally, extending the research to other industrial sectors could contribute to generalizing the results and identifying universal relationships in production management.

In conclusion, the study confirmed that optimizing production systems using computer simulation is an essential component supporting the decision-making process in a dynamically changing industrial environment. The results can serve as a valuable resource for managers and production engineers, assisting them in making strategic decisions regarding the expansion and optimization of systems.

Acknowledgements

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References

1. Asseco CEIT (2024). *Symulacja procesów [Simulation of processes]*. Retrieved from: <https://www.asseco-ceit.com/pl/symulacja-procesow/>, 31.10.2024.
2. Borshchev, A. (2013). *The Big Book of Simulation Modeling: Multimethod Modeling with AnyLogic 6*. Chicago: AnyLogic North America.
3. Borshchev, A., Filippov, A. (2004). *From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools*. The 22nd International Conference of the System Dynamics Society. Oxford, UK, pp. 23-27.
4. Chen, W., Hong, W., Zhang, H., Yang, P., Tang, K. (2022). *Wielowierszowe modelowanie symulacyjne dla symulacji zdarzeń dyskretnych: perspektywa optymalizacji*. IEEE Transactions on Automation Science and Engineering.
5. Cigolini, R., Pero, M., Rossi, T., Sianes, A. (2014). Łączenie konfiguracji łańcucha dostaw z wydajnością łańcucha dostaw: model symulacji zdarzeń dyskretnych. *Simulation Modelling Practice and Theory*, 40, pp. 1-11.
6. Daaboul, J., Castagna, P., Da Cunha, C., Bernard, A. (2014). Modelowanie i symulacja sieci wartości na potrzeby analizy strategicznej: podejście symulacji zdarzeń dyskretnych. *International Journal of Production Research*, 52(17), pp. 5002-5020.
7. DS-Technic. *Symulacja procesów produkcyjnych*. Retrieved from: <https://ds-technic.com/symulacja-procesow-produkcyjnych/>, 31.10.2024.
8. Dubaj, K. (2023). Praktyczne zastosowanie narzędzia FlexSim w modelowaniu symulacyjnym systemów produkcyjnych. *Zeszyty Naukowe Akademii Górnośląskiej*, Vol. 6, pp. 23-31. Retrieved from: https://www.gwsh.pl/content/biblioteka/org/zeszyty/ag/zn6/ZN6AG_Dubaj.pdf, 31.10.2024.
9. Greasley, A. (2017). *Simulation Modelling for Business*. London: Routledge.
10. Karwat, B., Rubacha, P., Stańczyk, E. (2022). Numerical Simulations of the Exploitation Parameters of the Rotary Feeder. *Management Systems in Production Engineering*, 30(4), pp. 348-354.
11. Kusiak, A. (2020). Convolutional and generative adversarial neural networks in manufacturing. *International Journal of Production Research*, 58, 1594-1604.
12. Lee, J., Kim, B.H. (2023). Digital Twin for Smart Steel Manufacturing. *Journal of Industrial and Production Engineering*.
13. Lidberg, S., Aslam, T., Pehrsson, L., Ng, A.H.C. (2020). Optymalizacja przepływów w fabrykach w świecie rzeczywistym przy użyciu zagregowanego modelowania symulacji zdarzeń dyskretnych. *Journal of Flexible Services and Manufacturing*, 32, pp. 888-912.
14. Mandolla, C. et al. (2022). Digital Twin Applications in Manufacturing: A Comprehensive Review. *Journal of Manufacturing Systems*.

15. Prajapat, N., Tiwari, A. (2017). Przegląd zastosowań optymalizacji montażu przy użyciu symulacji zdarzeń dyskretnych. *International Journal of Computer Integrated Manufacturing*, 30(2-3), pp. 215-228.
16. Sobottka, T., Kamhuber, F., Henjes, J., Sihn, W. (2017). *Studium przypadku dotyczące symulacji i optymalizacji opartej na planowaniu systemów produkcyjnych i logistycznych*. Konferencja Symulacji Zimowej (WSC), pp. 3495-3506.

CONSTRAINTS IN PRINTING INDUSTRY

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Purpose: The main objective of this paper is to identify typical constraints characteristic of the printing industry and to systematize them through quantitative research.

Design/methodology/approach: A literature review method and a quantitative survey conducted on a sample of 237 companies in the printing industry were used to solve the research problems. This study is both theoretical and empirical.

Findings: The answers obtained from the respondents, allowed the development of a systematic of constraints, and also helped to expand the knowledge of printing companies. A total of 26 constraints were included, which were divided into four categories: technical, market, social and organizational constraints. Also identified were the key constraints that companies of different sizes - small, medium and large - most often identify in their operations.

Research limitations/implications: The developed of a systematic of constraints applies only to the printing industry. It is a flexible tool, i.e., it must be regularly updated and adapted to changing market conditions and the specific needs of the organization, thus enabling effective identification and resolution of current problems.

Practical implications: The systematic of constraints is a practical tool that enables printing companies to understand what key constraining factors are affecting their operations and growth. The tool identifies and better understands the industry's major constraints, sensitizing companies to key issues that need to be addressed.

Originality/value: The value of the study lies in providing printing companies - regardless of their size - with a dynamic tool to identify the constraints blocking their growth. The article is aimed at industry professionals, managers and researchers who are looking for practical solutions and insights into current constraints affecting the printing sector.

Keywords: constraints, bottlenecks, printing industry, theory of constraints, TOC.

Category of the paper: research paper.

1. Introduction

In the printing industry, as in other industrial sectors, there are constraints that have a key impact on operational efficiency and the achievement of business goals. To identify these constraints, it is useful to ask a fundamental question: *what is preventing an organization from*

increasing the rate at which it achieves the purpose of its existence? Thus, a constraint can be defined as anything that prevents a system from performing better relative to the purpose of its existence (Scheinkopf, 2022) or anything that prevents a company from making more money and achieving a higher level of its goals (Azaria et al., 2023).

Constraints can take many forms. In the literature, there are many types of constraints that occur in companies (Goldratt, 1990; Cox, Spencer, 1998; McMullen, 1998; Reid, 2007; Woeppel, 2009; Lewandowski et al., 2018). Scheinkopf (2022) distinguishes between physical, organizational and mental constraints. Physical constraints, are resources that physically limit the system's ability to increase throughput. They can be located inside or outside the organization. An internal physical constraint occurs when an organization lacks the capacity or specific skills needed by the organization. External physical constraints include raw materials or the market. Another is organizational constraints, understood as rules that prevail in a company, but also measures that are used to evaluate the systems on which decisions, sometimes strategic ones, are made. Mental constraints are beliefs and assumptions that make us create and accept organizational constraints and adhere to them. Constraint is often confused with bottleneck, which is certainly an internal physical constraint. It may be defined as a resource whose capacity is less than required. It is worth noting that every bottleneck is a constraint, but not every constraint is a bottleneck. The presence of constraints significantly determines how effectively an enterprise can achieve its goals. Improper management of these constraints can lead to a number of consequences including downtime, built-up inventories, reduced productivity of the system as a whole (Urban, Rogowska, 2018), but most importantly, improper management of constraints distances us from a commercial company's main goal of making money today and in the future (Gupta et al., 2022; Cox et al., 2003; Cox, Spencer, 1998).

A concept that focuses on managing constraints in organizations is the Theory of Constraints (TOC) developed by Israeli physicist Eliyahu M. Goldratt. The methodology is not particularly new. Its origins can be traced back to the 1970s, when Goldratt and his team developed a production planning and control system, first called the Optimized Production Timetable (1979) and then, from 1982, as Optimized Production Technology (OPT) (Mabin and Balderstone, 2003). Introduced by E.M. Goldratt in the mid-1980s, a broad awareness and understanding of the TOC methodology was first achieved by people reading the book *The Goal: A Process of Ongoing Improvement* (Goldratt, Cox, 1984). The essence of TOC is to focus on the organization's most important goal and precisely identify the element that most blocks its achievement. Its basic premise is that the capacity of the entire organizational system is determined by the capacity of the constraint (Goldratt, 1990). An company can be compared to a chain that has a minimum of one link inhibiting its current potential and preventing it from increasing its performance. Thus, in any system, at any given time, there is only one area that limits the ability to achieve the intended goal. Otherwise, the company's activities would generate unlimited profits (Lewandowski et al., 2018). TOC is becoming popular among

managers because of its simplicity, which can be pointed out as: find the limitation of your system and improve its throughput, thus improving the performance of the whole system. This methodology of focusing exclusively on key constraints is extremely attractive - as it promises high efficiency and great results with the least possible expense (Urban, 2019). The TOC systems approach requires that you first understand the system, its goal, and measurements. Then you can apply the Five Focusing Steps (Cox, Schleier, 2010):

1. Identify the constraint(s).
2. Decide how to exploit the constraint(s).
3. Subordinate/synchronize everything else to the constraint(s).
4. If needed, elevate the system's constraint.
5. If the constraint has been broken, go back to step one. Do not let inertia become the constraint.

Properly identifying the key constraint (step 1) is the foundation of this concept, as it allows resources and activities to be focused on the areas that have the greatest impact on achieving the desired results. By accurately identifying these constraints, companies are able to direct their efforts to eliminate or mitigate these factors, leading to significant improvements in the overall system. Identifying constraints is essential for process improvement and achieving operational excellence, enabling organizations to operate effectively and make sound decisions to increase efficiency and accomplish strategic goals (Urban, Rogowska, 2020). Therefore, it is important to develop a systematic of constraints tailored to the specific characteristics of various industries. Each sector has its constraints. A systematic of constraints would allow organizations to direct resources more precisely to where their impact would bring the greatest benefits for operational efficiency.

The main objective of this paper is to identify typical constraints characteristic of the printing industry and to systematize them through quantitative research. The following research problem were formulated: what constraints exist in the printing industry in Poland? The literature review method and quantitative research were used to address the scientific problem. This study is both theoretical and empirical. The theoretical part presents the importance of identifying key constraints within an enterprise. The practical part then discusses the results of a study conducted on a Polish sample of 237 companies from the printing industry. The study concludes with a discussion of the results and conclusions.

2. Own research methodology

The aim of this study is to identify the typical constraints of the printing industry. For this purpose, two research methods were used: literature review and survey. The paper covers a fragment of a broader study in which the research tool was a survey questionnaire

consisting of 13 questions of a closed. The closed questions included a Likert scale. The survey was developed based on an extensive literature review aimed at identifying the constraints (their types) occurring in enterprises. The analysis considered not only the perspective of the production system but also the entire enterprise and its environment. The main technique used for the research process was the CAWI method. The electronic questionnaire was made available on the profitest.pl website. The survey was anonymous. The study was conducted from May to July 2022. A complete return of fully filled-in questionnaires was obtained. The research results are presented in the subsequent part of the scientific article.

3. Characteristics of the research sample

The subject of the conducted research were enterprises operating in the printing sector, involved in the production of various products. These enterprises represent an important research area due to their specific requirements, diverse production flows, and their economic significance in the economy. The study, conducted in 2022, included 237 respondents, each representing one enterprise. The survey covered companies from all over Poland, encompassing all provinces. The structure of the surveyed enterprises is presented in the figure 1.

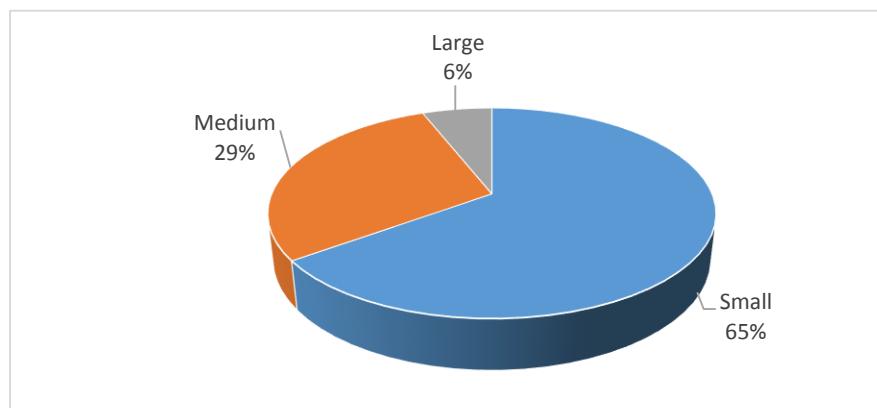


Figure 1. The structure of the surveyed enterprises.

Source: Own elaboration based on the research results.

The vast majority of respondents participating in the study were from the small enterprise sector, employing between 10 and 50 employees (154 entities). The smallest group consisted of large enterprises with more than 250 employees (15 entities). However, given that in 2020 there were only 18 representatives of this group in the printing industry market, it can be considered the most well-recognized group of surveyed entities. The last analyzed group consisted of 68 respondents, who were representatives of medium-sized enterprises employing between 50 and 249 employees. The presented structure of the surveyed enterprises reflects the share of company sizes in the printing industry, where the small enterprise sector

clearly dominates. The survey conducted did not include the microenterprise sector, employing fewer than 10 employees, due to the low technological advancement of these entities.

4. Analysis of research results

A broad literature review identified 16 constraints that may occur both within and outside the enterprise. These include: the scale of demand for products, applicable legal regulations, a limited number (monopoly) of suppliers, conflicts between different departments, improper flow of information, lack of synchronization between the sales and production departments, insufficient production space, the company's development policy, excessive product assortment variety, machine capability, outdated technology, mismatched technology, production planning system, delays in material delivery to the production station, problems with raw material deliveries from suppliers, and unavailability of workers.

Respondents were tasked with evaluating each constraint from the list using a five-point Likert scale, where the assigned values represented: 1 – does not occur, 2 – rather does not occur, 3 – difficult to say, 4 – rather occurs, 5 – occurs. Respondents were also asked to provide other factors as potential constraints that were not included in the question but may be relevant to the issue being analyzed. Ten entities participating in the study provided their own responses. Respondents identified the following factors as potential constraints for the enterprise: quality of courier deliveries, insufficient warehouse space (for production materials and finished products), customer requirements, availability of courier services, a large number of changes between the calculation and the final product, employee incompetence, employee engagement in their work, delays in files from customers, the business owner, and high capital intensity. The responses obtained from the respondents allowed for the development of a systematic of constraints and expanded the knowledge about enterprises in the printing industry. It is worth noting that a constraint is understood as a factor that blocks the development of an enterprise within the framework of the TOC. The systematic of constraints is a way of categorizing and grouping different types of constraints that may occur within an enterprise. The development of a constraint systematic is directly related to the TOC, as it can serve as one of its key tools.

Table 1 presents the systematic of constraints in the printing industry. These constraints have been divided into four categories: technical, market, social, and organizational constraints. A total of 26 constraints were considered, taking into account both the constraints from the list and the responses provided by the respondents. Each group contains between 4 and 8 items. The constraints were organized according to the number of responses rated as 5 – occurs for each, starting with the most frequent and ending with the least frequent. This division allows for a more detailed identification and understanding of the factors influencing the development of printing enterprises.

Table 1.*The systematics of constraints in the printing industry*

SYSTEMATICS OF CONSTRAINTS IN THE PRINTING INDUSTRY	
Technical	- machine capability - insufficient production space - delays in material delivery to the production station - excessive product assortment variety - outdated technology - mismatched technology - quality of subcontracted logistics services - insufficient warehouse space (for production materials and finished products)
Market	- scale of demand for products - applicable legal regulations - limited number (monopoly) of suppliers - customer requirements - availability of courier services - a large number of changes between the calculation and the final product
Social	- unavailability of workers - conflicts between different departments - employee incompetence - employee engagement in their work
Organizational	- problems with raw material deliveries from suppliers - production planning system - lack of synchronization between the sales and production departments - the company's development policy - improper flow of information - delays in files from customers - the business owner - high capital intensity

Source: own study.

The first group – *technical constraints* – refers to barriers that occur, especially where technology plays a key role in the production process. These constraints hinder the proper functioning of production processes, resulting from imperfections in the technologies and equipment used, as well as from insufficient space and infrastructure. They can affect both the production process itself and management or transportation systems.

The second group – *market constraints* – refers to barriers that arise from the conditions prevailing in the market (external factors). They hinder the proper functioning of a business due to variations in demand for products, legal regulations, availability of logistics services, customer requirements, and the number of suppliers in the market. These constraints can affect various aspects of the business, such as production, distribution, or sales. Market constraints often force businesses to adapt to new conditions.

The next group – *social constraints* – refers to barriers related to employees or the workforce that can hinder work and lead to irregularities in the functioning of the organization. These constraints are usually related to interpersonal relationships, employee engagement in their work, and their competencies.

The last group – *organizational constraints* – refers to barriers that arise from management issues within the company or due to the improper functioning of its organizational structures. These constraints hinder the proper functioning of the unit, resulting from imperfections in

internal processes. They can affect aspects such as planning, coordination, and control of activities.

The results of the research allowed for the observation of interesting relationships between entities. Table 2 presents the key constraints that companies of different sizes – small, medium, and large – most often identify in their operations.

Table 2.

The size of the company and the type of potential constraints

The size of the company	Constraints	Percentage of indications
small	applicable legal regulations	60%
	scale of demand for products	58%
	machine capability	48%
medium	the scale of demand for products	57%
	machine capability	54%
	problems with raw material deliveries from suppliers	53%
large	machine capability	80%
	scale of demand for products	60%
	applicable legal regulations	60%
	limited number (monopoly) of suppliers	60%

Source: own study.

The scale of demand for products and machine capability were identified as key constraints by all respondent groups, highlighting their fundamental importance in the context of business operations regardless of company size. In the case of small company, 60% of respondents highlight applicable legal regulations as key constraints affecting their operations. Additionally, 58% point to the scale of demand for products, and 48% to machine capability. These data suggest that small businesses should pay particular attention to changes in applicable legal regulations and the efficiency of their technology. Adapting to these requirements may involve significant costs and require substantial time investments, which ultimately affects their ability to respond quickly to changing market conditions. For medium-sized businesses, the scale of demand for products (57%) and machine capability (54%) are the dominant constraints. This indicates the need for greater flexibility in managing production processes and the necessity of closely monitoring market demand. Additionally, 53% of respondents from this group point to problems with raw material deliveries from suppliers, which also affects production stability. In large businesses, machine capability is a key constraint highlighted by 80% of respondents. Large companies often specialize in printing specific types of products, which may be linked to higher customer demands and quality standards. This can affect the execution of a larger number of complex orders that require diverse and more advanced processes, as well as coordination of multiple machines and workers. This means there is a higher frequency of machine setup changes, which consequently extends downtime and impacts overall machine performance. Despite having greater financial resources that allow for investment in modern machinery, these factors can still affect the efficiency of production processes. The scale of demand for products, applicable legal regulations, and limited number

(monopoly) of suppliers (60% each) also play a role, indicating that these companies must manage complex operational processes and ensure the efficiency of their production technology.

5. Discussion and conclusions

The printing industry faces numerous constraints that significantly impact the efficiency and growth potential of businesses. Precise identification and analysis of these constraints are essential for companies to fully leverage their potential and achieve their set goals. The developed systematics of constraints enables the identification and resolution of various issues that affect the functioning of businesses. It is a tool that allows organizations to better understand which internal and external factors may hinder their operations. As a result, businesses can analyze what actions should be taken to eliminate these constraints or at least minimize their impact.

It is important for printing companies to treat the systematics of constraints not as a set of rigid rules, but as a flexible tool for identifying and solving current problems. This systematics should be understood as a dynamic process that requires regular updates and adjustments to changing market conditions and the internal needs of the organization. By implementing TOC, printing companies should adopt an approach based on continuous improvement, where they constantly identify and eliminate constraints. This enables the systematic increase of efficiency and operational effectiveness, contributing to their long-term growth and competitiveness.

The systematics of constraints thus becomes a practical tool that allows printing companies to understand which key limiting factors affect their operations and development. This tool helps identify and better understand the main constraints in the industry, sensitizing companies to the key issues that need to be addressed. The systematics of constraints is important in the context of TOC because it enables more precise identification of constraints within the company and the development of strategies that will allow for their elimination or reduction.

It is important to emphasize that, according to the principles of TOC, the systematics of constraints allows companies to focus resources on key areas that can bring the greatest benefits. With more targeted management, organizations can operate more efficiently and respond more quickly to new challenges.

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References

1. Azaria, S., Ronen, B., Shamir, N. (2023). Justice in time: A theory of constraints approach. *Journal of Operations Management*, Vol. 69, No. 7, pp. 1202-1208, doi: 10.1002/joom.1234
2. Cox, J.F. III, Schleier, J.G. (2010). *Theory of constraints handbook*. New York: McGraw-Hill.
3. Cox, J.F., Blackstone, J.H., Schleier, J.G. (2003). *Managing operations: A focus on excellence*. Great Barrington, MA: North River Press.
4. Cox, J.F., Spencer, M.S. (1998). *The Constraints Management Handbook*. Boca Raton, FL: The St Lucie Press/APICS Series on Constraints Management.
5. Goldratt, E.M. (1990). *What Is This Thing Called the Theory of Constraints and How Should It Be Implemented?* Croton-on-Hudson, NY: North River Press.
6. Goldratt, E.M., Cox, J.F. (1984). *The Goal: A Process of Ongoing Improvement*. Crotonon-Hudson, NY: North River Press.
7. Gupta, M., Digalwar, A., Gupta, A., Goyal, A. (2022). Integrating Theory of Constraints, Lean and Six Sigma: a framework development and its application. *Production Planning & Control*, Vol. 35, No. 3, pp. 238-261, doi: 10.1080/09537287.2022.2071351
8. Lewandowski, J., Skołud, B., Plinta, D. (2018). *Organizacja systemów produkcyjnych*. Warszawa: PWE.
9. Mabin, V.J., Balderstone, S.J. (2003). The performance of the theory of constraints methodology – Analysis and discussion of successful TOC applications. *International Journal of Operations & Production Management*, Vol. 23, No. 6.
10. McMullen, T.B. (1998). *Introduction to the Theory of Constraints (TOC) Management System*. Boca Raton, FL: St Lucie Press.
11. Reid, R.A. (2007). Applying the TOC five- step focusing process in the service sector: A banking subsystem. *Managing Service Quality*, Vol. 17, No. 2, pp. 209-234.
12. Scheinkopf, L. (2022). *Logika zmiany: narzędzia myślowe dla managerów*. Warszawa: Mint Books.
13. Urban, W. (2019). TOC implementation in a medium-scale manufacturing system with diverse product rooting. *Production & Manufacturing Research*, Vol.7, No. 1, pp. 178-194, DOI: 10.1080/21693277.2019.1616002

14. Urban, W., Rogowska, P. (2018). *The case study of bottlenecks identification for practical implementation to the theory of constraints*. XV International Conference: Multidisciplinary Aspects of Production Engineering: MAPE 2018: Conference proceedings. PANOVA 2018, t. 1, pp. 399-405. DOI:10.2478/mape-2018-0051
15. Urban, W., Rogowska, P. (2020). Methodology for bottleneck identification in a production system when implementing TOC. *Engineering Management in Production and Services*, Vol. 12, No. 2. DOI: 10.2478/emj-2020-0012.
16. Woepfel, M.J. (2009). *Jak wdrożyć teorię ograniczeń w firmie produkcyjnej: Poradnik praktyka*. Warszawa: MintBooks.

GREEN INVESTMENTS AS A WAY TO SUPPORT SUSTAINABLE DEVELOPMENT OR TO EARN?

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Purpose: This paper is aimed at analyzing development trends of green investments and identifying determinants of increased interest in investments related to sustainable development.

Design / methodology / approach: In this paper, an attempt was made to answer the following question: how are green investments identified and what the drivers behind the investors' selection of investment in sustainable products are? The following research methods were employed: literature review, secondary source analysis and deductive reasoning.

Findings: The green investment market has been developing dynamically and exponentially. At present, the European market is the most active one. When investing in sustainable entities' instruments, investors consider information concerning fund allocation directions. 72% of respondents verify if investment strategies related to their funds are consistent with the sustainable development goals. Moreover, they equate them with satisfactory profits. 60% of survey respondents earned profits on green investments more than on investments in products not connected with ESG.

Social implications: This article presents the essence and benefits of green investments. Increased social awareness allows to understand and identify products to which the investors may allocate their funds to ensure harmony with eco-friendly, pro-social, and ethical attitudes and values.

Originality / value: This paper has cognitive values as it extends the existing knowledge with the aspect of green investment identification and the drivers behind the choice of that investment direction by investors.

Keywords: green investments, investors, ESG funds.

Category of the paper: conceptual paper.

1. Introduction

Environmental protection and sustainable development are ones of the most important challenges today. Slowing down climate changes and their effects has become a priority for politicians, scientists and the entire society. The Paris Agreement, or the United Nations

Framework Convention on Climate Change, selected as its major objective reduction of the global temperature rise by the end of this century below two degrees Celsius when compared to the level before the industrial era and effort to keep temperature rise below 1.5 degrees (https://unfccc.int/sites/default/files/english_paris_agreement.pdf). However, those activities require much investment. Consequently, an important task for financial systems emerged, relating to the transformation of cash flows from investors towards the sustainable development. This transformation takes place using financial instruments within the so-called green (sustainable) investments.

For five years, there has been noticeably increased interest in green investments. Sustainable instruments have no longer been a niche market, but have become a more and more attractive fund allocation target. According to the report published by PwC in 2022, the value of ESG funds reached USD 18.4 tn, i.e. 14.4% of all assets. It is expected that the upward trend will be maintained and that the ESG share in the total funds will reach 21.5% in 2026 (Exponential Expectations for ESG, 2022).

As the knowledge of climate threats grows, more and more investors become aware of their investments' impact on the environment and the society. Moreover, there is a growing group of investors who perceive long-term benefits of investment in business entities which consider sustainable development to be a priority in their strategy. Such an approach is good not only for the environment and the society, but also may result in high financial profits long-term.

The objective of this paper to analyze development trends of green investments and identify determinants of increased interest in investments related to sustainable development. Consequently, in this paper, an attempt was made to answer the following question: how are green investments identified and what the drivers behind the investors' selection of investment in sustainable products are?

The following research methods were employed: literature review, secondary source analysis (Exponential Expectations for ESG, Asset and Wealth Potential Management, PWC Report, 2022) and deductive reasoning.

2. Sustainable development essence

It is not easy to define sustainable investments. Reference works do not offer any clear definition of that term. The difficulty of defining green investments results from the ambiguity of their constituents. Neither the term "investments", nor "green" have clear definitions.

The investments are most often defined as involvement of money or capital into an enterprise (business, project, real property etc.) with an expectation to earn extra income or profit. The term "green" is a bit more complex. In the most general terms, this is associated with activities aimed at minimizing adverse climate changes. However, in practice and science,

green investments may be a subset of a broader area which is why they are also termed as follows:

- ESG investments (aimed at environmental, social and governance-related goals);
- SRI investments (socially responsible investments or sustainable investments);
- environmentally-friendly investments (eco-friendly ones);
- investments in the so-called green sectors, including water, agriculture etc.

The definitions of “greenness” may refer to *ex ante* activities (e.g. any enterprises related to sustainable energy, energy efficiency or water management) or *ex post* activities, based most often on specific outcomes of eco-friendly activities. Moreover, there are some qualitative and quantitative definitions which attempt to measure different “greenness” levels. The latter require an index or measure concerning e.g. greenhouse gas emissions, energy efficiency, recycling and waste management.

Table 1.

Green fund definition examples

Author	Green investment definition
Eyraud et al., 2013	investments required to reduce greenhouse gas emissions and air pollution with no significant reduction of production and consumption of non-energy goods
Utz, 2015	eco-friendly investments referring to social investments aimed to improve the natural environment condition
Escrig-Olmedo, Rivera-Lirio, Munoz-Torres, 2017	environmental, social, and governance investing, responsible investments, and socially responsible investments
Yen, 2018	investments aimed primarily at contributing to the improved environment
Du, H.S. et al., 2019	environmental investments referring to social investments aimed to improve the environment condition

Source: own compilation based on Eyraud et al., 2013; Utz, 2015; Escrig-Olmedo et al., 2017; Yen, 2018; Du, H.S. et al., 2019.

The analysis of the green fund definition presented in Table 1 reveals that although they differ, they share the same investment goal, i.e. the favorable impact on the environmental protection and sustainable development promotion.

The terminological problems relating to green investments result in difficulties identifying instrument connected with the environmental protection and sustainable development. This is why financial institutions and some regulatory bodies have developed solutions which help them define green investments. They use the term “green” when the investment meets specific criteria. Generally speaking, there are three criteria most often used to classify instruments as eco-friendly: negative screening, best in class and impact investment. Due to the absence of generally applicable regulations, the applicability of criteria and approach differs slightly depending on the business entity (Inderst et al., 2021).

The first criterion used to identify green investments is negative screening. Those criteria are identifiable determinants used to eliminate selected sectors, companies or states from the so-called sustainable investment directions. The negative screening is most often based on standards. Those criteria eliminate entities which do not follow international treaties,

i.e. violating human rights, regulations prohibiting child labor, concerning production and supply of controversial weapons (included e.g. in the Convention on Cluster Munitions, Chemical Weapons Convention). They may also refer to negative screening based on values. They cover institutions that derive more than 5% of their revenue from conventional weapons and firearms, tobacco production, gambling, or adult entertainment. Furthermore, companies that derive more than 20% of their revenue from tobacco distribution or conventional weapons support systems and services will be excluded. In addition, a revenue limit of 20% is usually applied to investments in coal (coal mining and coal-based electricity generation), a revenue limit of 5% in arctic oil and gas as well as a revenue limit of 10% in oil sands (CSSP and Southpole, 2016).

Another criterion of considering investments green is the “best in class approach”. This approach entails identification of instruments characterized with the highest ESG standards in the sector or industry. Relating to investment in entities’ securities, this criterion enables to isolate the entities whose strategies and ongoing decisions consider environmental, social, and governance aspects. The notion of “best in class” is connected with the belief that companies with robust ESG practices stand better chance of achieving long-term financial success and stability when compared to those with less robust ones (Zhang, Yousaf, 2020; Wang et al., 2018). Their level may shape the ability to finance new investments from funds provided by investors for whom the sustainable development policy is important. However, any activities non-compliant with the ESG idea, including workplace discrimination, emission of environmentally harmful gases or funding political campaigns may compromise the company reputation in the stakeholders’ eyes. In this way, environmental marking ensures certain confidence relating to the wallet and funded projects.

For investors, adoption of the “best in class approach” is related to prioritizing their investments, i.e. sustainable development goals and social responsibility, striving to obtain financial profits at the same time. This allows to adapt the investment wallet to their own values and preferences. When selecting instruments, investors often use ESG evaluations and rankings provided by such organizations as MSCI, Sustainalytics and S&P Global.

Impact investing is a green investment type referring to investing in business entities which work towards generating measurable, positive social and environmental impact with the suitable rate of return. Generally speaking, this refers to companies, organizations and funds which solve important problems, including poverty, climate changes and access to healthcare. As impact investing is quite difficult to achieve through simply selecting publicly listed companies, impact investing strategies are usually closely tied to private equity-, infrastructure- or venture capital funds. Examples of sectors where entities are benefiting from impact investing are renewable energy, clean technologies. Investing in companies working to reduce dependence on fossil fuels and increase the use of renewable energy sources may help minimize the risk of climate changes (Costa, 2021).

To sum up, despite the absence of unequivocal definitions of green investments, you can find a common denominator shared by all of them. This is spending funds towards sustainable development (Han et al., 2020). In this paper, a broad approach to the definition is adopted, considering that the “green” investments are the environmental, social and corporate governance-related ones (ESG) (Utz, 2015; Escrig-Olmedo et al., 2017).

The green investment definition specifies drivers prompting investors to select those instruments. The first driver is the objective relating to funding activities connected with environmental protection and sustainable development promotion. In recent years, the increased awareness and concerns concerning climate changes and their potential impact on economic and social welfare result in growing interest in sustainable funds. Eco-friendly and socially responsible investors want to participate in funding enterprises reducing and/or slowing down adverse effects of climate changes (Dutta et al., 2020). By allocating their funds to assets marked sustainable, they intend to support business entities in the so-called green transformation. Funding environmentally friendly investments, including e.g. reduced carbon dioxide emission, green energy and green technology, requires high expenditure and their rate of return is long-term. However, the funds flow through green instruments from investors to entities requiring capital to fund such activities. This means that green investments which are a key factor of business entities’ sustainable development attract trust of investors who want to support enterprises in line with environmental ethics (Chen, Ma, 2021; Eyraud et al., 2013, Mangla et al., 2014; Zhu et al., 2016).

Green investments are a way to earn as well. This is consistent with the concept of investments in finance which are considered a way to allocate in order to generate profit. Hence, investments in projects and business models relating to environment protection and sustainable development are more and more often perceived as an opportunity to earn income in line with one’s eco-friendly, pro-social and ethical values. It is disputable, however, if investment in financial instruments which are climate- and society-friendly entails lower effectiveness (rate of return).

3. Research methodology

A review of the literature to date indicates that studies treating green investment as physical investment dominate. These studies analyze them in the context of foreign direct investment, financial development, and green technology innovation (Kharb et al., 2024; Wang, Yu, Zhang, 2025; Liu, Fang, 2024; Casciello et al., 2024; Zhang, Sun, 2024). Another category of research that has been undertaken in quite large numbers is the treatment of investment as the placement of money in financial instruments. In this regard, research focuses on analyses of financial instrument prices in the context of climate risk (Dutta et al., 2023), volatility of financial

instrument prices (Doğan, et al., 2025), impact on stock market development (Bouteska et al., 2025), among others. These analyses use secondary data from the securities price market and are based on the use of quantitative methods. The same type of methods are also used in bibliometric studies (Mudalige, 2023). Few studies address the issue of green investments from the point of view of investors, specifically analyzing the benefits in green ventures. These are studies using statistical analyses of listed companies' data (Morgan Stanley, 2019; CSSP& Southpole, 2016). According to what we were able to find, there are no studies referring to the problem of sustainable investments from the side of investors using primary data.

Therefore, the aim of this article was to analyze the development trends of green investments and identify the determinants of the growth of interest in sustainability-related investments using survey data. For this purpose, data from the PWC Report: Expotential expectations for ESG was used. This report was produced in 2022 as the result of a global survey of 250 institutional investors and 250 asset managers, representing nearly half of global assets under management (AuM). The value of this data is that it is international in nature and was obtained through a questionnaire, so it was primary data.

The following research methodology was adopted in this study. Literature review allowed to learn the key theoretical problems and present the essence of topics related to green investments. In this paper, a cause and effect analysis was used to present the determinants of the ESG instrument market development from the investors' perspective and a logical analysis consisting in the search for logical relations between the causes and effects of those changes. Moreover, based on data in PWC Report, an analysis was carried out of statistical data concerning the green investment development and drivers encouraging investors to select that financial instrument type.

4. Analysis of the development and determinants of green investment instruments — study results

The analysis concerning green investment development reveals that they grow dynamically. According to data presented in figure 1, ESG-oriented funds increase much faster than the market as a whole. The global value of ESG funds grew from USD 2,2 tn in 2015 to USD 18.4 tn in 2021. Their value is expected to reach USD 33.9 tn in 2026. To compare, the total value of AuM in 2015 was USD 76.3 tn, in 2021 USD 127.5 tn, and in 2026 it is anticipated to reach USD 157.2 tn.

The share of ESG assets in total assets grew from 2.9% in 2015 to 14.4% in 2021. It is anticipated that it will have grown to 21.5% of all AuM (Assets under Management) by 2026. The percentage growth expressed by CAGR (compound annual growth rate) in 2015-2021 reached 8,9% for AuM, and in 2021-2026, it is forecast to reach 4.3%. However, for ESG, it reached 42.7% and is forecast to grow by 12.9% respectively.

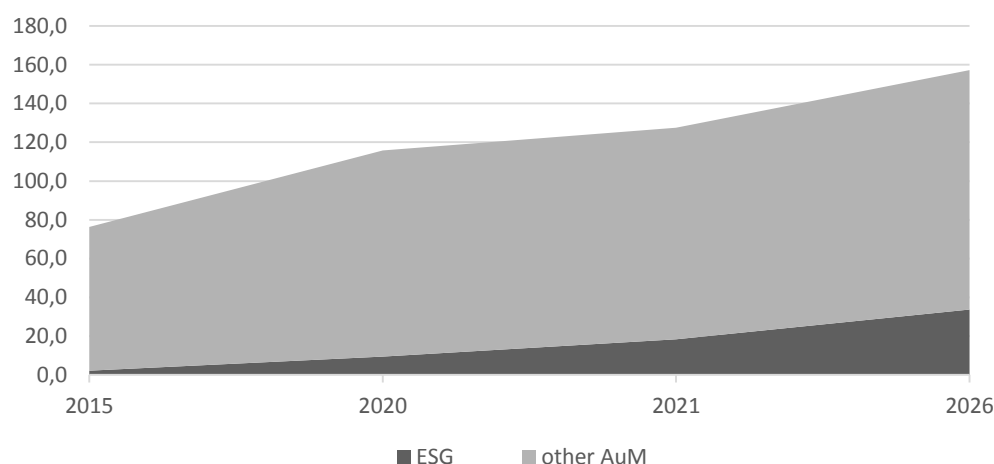


Figure 1. Growth dynamics of ESG and other AuM funds.

Source: own compilation based on PWC Global ESG and AWM Market Research Centre analyses, ESG Global 2022.

When it comes to geographical distribution, the most important market for global ESG as assets under management is the European one. In 2020, it held 50% of all ESG funds, with as much as 70% in 2021. This is interesting as the largest market for total AuM funds is U.S. (67 trillion USD).

According to studies, the ESG instrument market will also grow dynamically outside Europe. 81% of institutional investors in U.S. plan to increase their allocations to ESG products in two years which is forecast to increase their share to 31% in 2026 (North America). Other regions of the world also plan green investment development. Asia and Pacific are expected to increase their share to 10%. However, the green investment share in Middle America and Middle East and Africa will grow to 1% of the global ESG market.

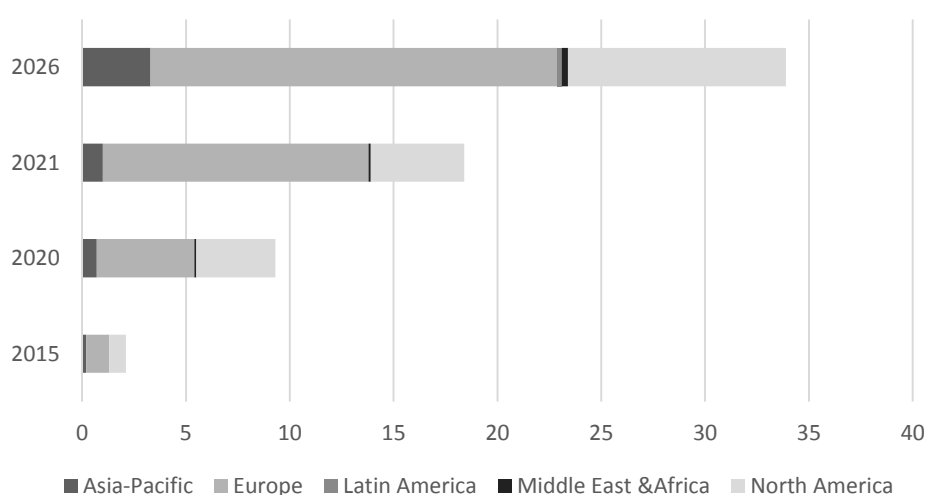


Figure 2. ESG funds by geographical distribution.

Source: own compilation based on PWC Global ESG and AWM Market Research Centre analyses, ESG Global 2022.

Trying to find an answer to the question concerning the drivers behind the dynamic development of ESG funds, we look at the study results which indicate that nine out of ten respondents managing assets believe that the inclusion of ESG in their investment strategy will improve overall profits. Moreover, most institutional investors (60%) declare that ESG investments have already brought them higher profits than their non-ESG counterparts (figure 3). However, just 14.4% of respondents claim that green investments contributed to lower profits when compared to non-ESG investments.

■ net positive ■ similar ■ net negative

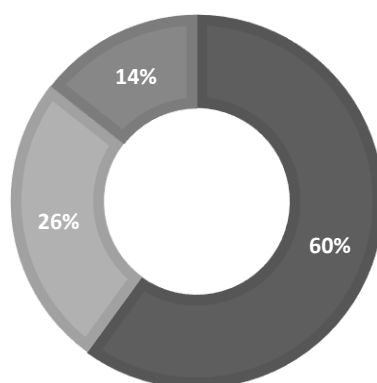
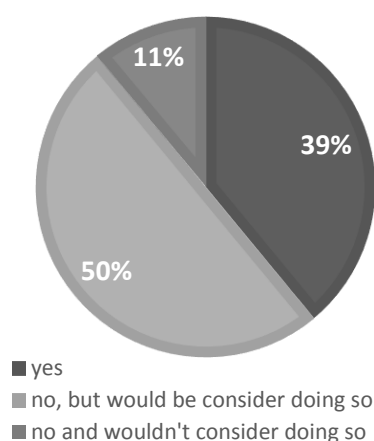


Figure 3. Yields on ESG products in comparison to their non-ESG equivalents.

Source: own compilation based on PWC Global ESG and AWM Market Research Centre analyses, ESG Global 2022.

ESG INVESTMENTS STRATEGIES



CORPORATE ESG EFFORTS

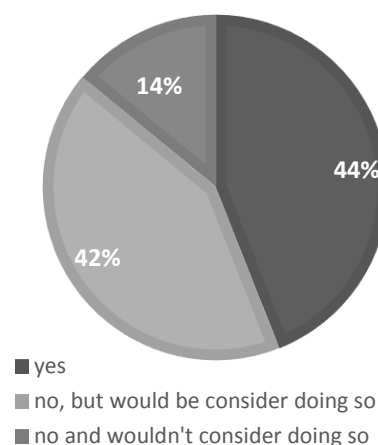


Figure 4. Would investors refuse to cooperate with the asset manager due to shortcoming in their ESG investments strategies or ESG investments?

Source: own compilation based on PWC Global ESG and AWM Market Research Centre analyses, ESG Global 2022.

When we analyze the objectives which the green investment funds are spent on, the studies indicate that more than seven out of ten institutional investors (72%) verify ESG investment strategy of asset managers. However, when answering the question whether investors would

refuse to cooperate with the asset manager due to shortcoming in their ESG investment strategies, 39% has already refused or stopped, and 50% said “no, but would be consider doing so” (figure 4). When asked about the refusal to cooperate or stopping cooperation due to shortcoming in their corporate ESG efforts, 44% said that they have already done that and 42% said “no, but would consider doing so”.

Therefore, considering the sustainable development goals is an important determinant for investors. As more and more entities are interested in green investments, the priority for asset managers (76%) is the opportunity to transform the existing products to make it possible to mark them as ESG-oriented. The conversion may refer to compliance with the Sustainable Finance Disclosure Regulation (SFDR), Article 8 and 9 ED or the actual alignment with the stakeholders’ expectations in other areas. However, transformation entails extra costs. 78% of responding investors indicated that they are willing to pay more for ESG funds. 57% would accept payment increase by 0.2 to 0.4%. The studies reveal also that investors would accept ESG inclusion in performance-related fees. More than one half (52%) of investors would be willing to link remuneration with ESG performance. Two third (67%) of them would accept ESG premium of 3% to 5%, and 25% a premium lower than 3%. Only few (8%) of them would be willing to pay 5% and more which are charged by some asset managers.

5. Discussion and conclusions

According to the presented survey results, the green investment market has been developing dynamically and exponentially. At present, the European market is the most active one. It is forecast that the increased activity of ESG funds in subsequent years will be more and more noticeable in the United States and Asia-Pacific.

A characteristic feature of green investments is their objective, i.e. funding activities relating to sustainable development. The surveys show that when investing in sustainable entities’ instruments, investors consider information concerning fund allocation directions. According to the results, close to 90% of respondents have already rejected or would reject cooperation with the asset manager due to shortcoming in their ESG investments strategies or ESG investments. The results are consistent with earlier publications which claimed that one fourth of people born in 1981–1996 perceive sustainable investing as the most important factor when selecting investment products (https://www.ey.com/en_gl/sustainability-financial-services). Promoting sustainable development and eco-friendly activities brings about changes in investors’ decisions as more and more people choose eco-friendly instruments and not traditional ones (Xing, Xia, Guo, 2019).

When choosing to invest in ESG, investors are led by the willingness to earn. The major property of all investments is the aim to obtain a satisfactory rate of return. According to the presented results, 60% of survey respondents earned profits on green investments more than on investments in products not connected with ESG. Moreover, most respondents identify their future investments in ESG instruments with higher profits. This indicates a growing interest of investors in green products because of economic results. This is further confirmed by data showing that investors are even willing to pay higher premiums. This is a new trend as earlier studies indicated ambiguous approach to ESG instrument profitability. According to the studies by the Federal Office for the Environment (FOEN), investment in environmentally-friendly financial instruments did not bring any inferior profits. On the contrary, at least one half of respondents declared that they were higher (CSSP & Southpole, 2016). Other analyses (Morgan Stanley, 2019) indicated that the profits from the so-called green investments do not differ significantly from the traditional ones but they are exposed to fewer fluctuations than the instruments valued based on the prices of crude oil or other fossil fuels (Rydzewska, 2023). Recent studies indicate that the impact of climate risk is positive on the returns of green energy assets, but negative on their volatility (Dutta et al., 2023).

To sum up, from the investors' perspective, investments in projects and business models relating to climate protection and sustainable development are becoming more and more attractive investment direction. They are considered an earning opportunity compliant with ethical rules and standards.

It should be stressed, however, that there are some obstacles to the green investments despite their growing popularity. Complex and discrepant regulations concerning the product classification as ESG hamper green instrument identification. The need for reliable, transparent data presented in reports by entities identifying themselves with activities towards sustainable development is also mentioned more and more often. Due to the growing demand for ESG investment products, investors complain about difficulties finding attractive and relevant investment opportunities. They claim that assets managers should be more proactive when developing new ESG products.

The considerations conducted in the paper and the conclusions formulated:

- contribute to the development of theory on instruments supporting climate protection actions, including but not limited to financial instruments included in the so-called green investments,
- in the management aspect, they indicate the need to improve the processes related to the development of legal frameworks, education and development of financial instruments for activities related to sustainable development,
- from the social point of view, they indicate the need for further support for activities, including those of a financial nature, in the field of pro-ecological activity, due to their social importance.

A limitation of this paper is the use of secondary data which reduce the statistical data analysis opportunities to the ones presented in the report. They include information on ESG funds without identifying individual products and their benefits. They fail to present sectors where the green instruments are used most often.

It should be emphasized, however, that the green fund notion is a developing topic both in the theoretical and in the practical aspect. The paper may therefore serve as a basis for further analysis relating to the development of instruments used to finance pro-ecological and pro-community investments.

References

1. Bouteska, A., Bhuiyan, F., Sharif, T., Miftah, Badir, B., Abedin, M. (2025). Impact of green bonds on traditional equity markets. *Research in International Business and Finance*, Vol. 73, DOI 10.1016/j.ribaf.2024.102606
2. Casciello, R., Santonastaso, R., Prisco, M., Martino, I. (2024). Green innovation and financial performance. The role of R&D investments and ESG disclosure. *Corporate Social Responsibility and Environmental Management*, Vol. 31, Iss. 6, pp. 5372-5390, DOI 10.1002/csr.2862
3. Chen, Y., Ma, Y. (2021). Does green investment improve energy firm performance? *Energy Policy*, 153, 112252.
4. Costa, J. (2021). Carrots or Sticks: Which Policies Matter the Most in Sustainable Resource Management? *Resources*, Vol. 10(12).
5. CSSP und Southpole (2016). *Klima freundliche Investitionstrategien und Performance. Studie im Auftrag des Bundesamts fur Umwelt (BAFU)*. Vaduz/Zuroch.
6. Doğan, B., Ben, J., Tiwari, A.K., Abakah, E.J.A. (2025), Asymmetry in returns and volatility between green financial assets, sustainable investments, clean energy, and international stock markets. *Research in International Business and Finance*, Vol. 73. DOI 10.1016/j.ribaf.2024.102626
7. Du, H.S., Zhan, B., Xu, J., Yang, X. (2019), The influencing mechanism of multi-factors on green investments: A hybrid analysis. *Journal of Cleaner Production*, 239, 1-12.
8. Dutta, A., Jana, R.K., Das, D. (2020), Do green investments react to oil price shocks? Implications for Sustainable Development. *Journal of Cleaner Production*, 266(2), DOI:10.1016/j.jclepro.2020.121956
9. Dutta, A., Bouri, E., Rothovius, T., Uddin, G.S. (2023). Climate risk and green investments: New evidence. *Energy*, 265, 126376.
10. Escrig-Olmedo, E., Rivera-Lirio, J.M., Munoz-Torres, M.J., Fernandez-Izquierdo, M.A. (2017). Integrating multiple ESG investors' preferences into sustainable investment:

- A fuzzy multicriteria methodological approach. *Journal of Cleaner Production*, 162, 1334-1345.
11. Expotential expectations for ESG. Assetand wealth potential management. Raport PWC (2022).
 12. Eyraud, L., Clements, B., Wane, A. (2013). Green investment: Trends and determinants. *Energy Policy*, 60, 852-865.
 13. Ghosh, A., Sarmah, S.P., Kanauzia, R.K. (2020). The effect of investment in green technology in a two echelon supply chain under strict carbon-cap policy. *Benchmarking: An International Journal*, Vol. 27, No. 6, pp. 1875-1891. <https://doi.org/10.1108/BIJ-10-2019-0439>
 14. Han, S.R., Li, P., Xiang, J.J. et al. (2022). Does the institutional environment influence corporate social responsibility? Consideration of green investment of enterprises—evidence from China. *Environmental Science and Pollution Research*, 29, 12722-12739 <https://doi.org/10.1007/s11356-020-09559-6>
 15. https://unfccc.int/sites/default/files/english_paris_agreement.pdf
 16. https://www.ey.com/en_gl/sustainability-financial-services
 17. Inderst, G., Kaminker, C., Stewart, F. (2012). Defining and Measuring Green Investments: Implications for Institutional Investors' Asset Allocations. *OECD Working Papers on Finance, Insurance and Private Pensions*, No. 24, OECD Publishing. <http://dx.doi.org/10.1787/5k9312twmn44-en>
 18. Kharb, R., Saini, N., Kumar, D. (2024). Driving environmental sustainability in emerging economies: The nexus of green finance, foreign direct investment, financial development, and green technology innovation. *Business Strategy and Development*, Vol. 7, Iss. 4. DOI 10.1002/bsd2.70008
 19. Liu, M., Fang, X. (2024). Does green financing promote outward FDI in enterprises? Evidence from China. *Journal of Environmental Management*, Vol. 370, DOI 10.1016/j.jenvman.2024.122991
 20. Mangla, S.M., Madaan, J., Sarma, P.R.S., Gupta, M.P. (2014). Multi objective decision modelling using interpretive structural modeling for green supply chains. *International Journal of Logistics Systems*, 17(2), 125. <https://doi.org/10.1504/IJLSM.2014.059113>
 21. Mudalige, H.M.N.K. (2023). Emerging new themes in green finance: a systematic literature review. *Future Business Journal*, 9, 108. <https://doi-1org-1uhffzpel02ab.han.polsl.pl/10.1186/s43093-023-00287-0>
 22. Rydzewska, A. (2023). Climate protection and sustainable development as an investment for the future from individual investors' perspective. *Zeszyty Naukowe Politechniki Śląskiej. Organizacja i Zarządzanie*, 171, pp. 139-155.
 23. Siddiki, A.Z., Baten, A., Billah, M. et al. (2019). The genome of the Black Bengal goat (*Capra hircus*). *BMC Research Notes*, 12, 362, <https://doi.org/10.1186/s13104-019-4400-3>

24. *Sustainable Reality: Analyzing Risk and Return of Sustainable Funds* (2010). Morgan Stanley, August 2019.
25. Utz, S.W. (2015). Tri-criterion modeling for constructing more-sustainable mutual funds. *European Journal of Operation Research*, 246, 331-338.
26. Wang, L., Yu, X., Zhang, Y. (2025), The effects of outward foreign direct investment on green technological innovation: A quasi-natural experiment based on Chinese enterprises. *Environmental Impact Assessment Review*, Vol. 110, DOI 10.1016/j.eiar.2024.107666
27. Wang, K., Zhang, M.-H., Tsai, S.-B., Wu, L.-D., Xue, K.-K., Fan, H.-J., Zhou, J., Chen, Q. (2018). Does a Board Chairman's Political Connection Affect Green Investment? From a Sustainable Perspective. *Sustainability*, 10, 58.
28. Xing, G., Xia, B., Guo, J. (2019). Sustainable Cooperation in the Green Supply Chain under Financial Constraints. *Sustainability*, 11(21), 5977, <https://doi.org/10.3390/su11215977>
29. Yen, Y.-X. (2018). Buyer–supplier collaboration in green practices: The driving effects from stakeholders. *Business Strategy Environment*, 27, 1666-1678.
30. Zhang, W., Sun, Ch. (2024), Do multinational enterprises' overseas investment activities promote their green transition performance? Evidence from Chinese listed companies. *Structural Change and Economic Dynamics*, Vol. 71, pp. 594-608, DOI 10.1016/j.strueco.2024.09.007
31. Zhang, X., Yousaf, H.A.U. (2020). Green supply chain coordination considering government intervention, green investment, and customer green preferences in the petroleum industry. *Journal of Cleaner Production*, 246, 118984.

STRATEGIC PARTNERSHIPS IN THE DEVELOPMENT OF THE POLISH BIOTECHNOLOGY INDUSTRY

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Purpose: Identification of causative factors and the resulting benefits regarding strategic partnerships in developing biotechnology enterprises in Poland.

Design/methodology/approach: Analysis of the literature on the subject, in-depth interviews, case studies and participant observations.

Findings: Effective strategic partnerships in Poland are few. They intertwine with other forms of cooperation, striving to create an innovation ecosystem that can increase the commercialisation of the work being carried out.

Research limitations/implications: The biotechnology enterprise sector does not maintain a register of strategic partnerships. Enterprises do not willingly disclose newly developed technologies. The research is of a pilot nature and requires continuation.

Practical implications: No register of strategic partnerships could guide the government in developing cooperation. Identify the sector's needs and measure the effectiveness of concluded partnerships (evaluation) and the directions of collaboration undertaken.

Originality/value: Identification of strategic partnerships in the biotechnology industry in Poland compared to other countries.

Keywords: strategic partnership; cooperation; innovation; biotechnology.

Category of the paper: Research paper.

1. Introduction

Biotechnology is a discipline that has a significant impact on modernisation. It can be a source of many inspiring innovations. Therefore, it requires reasonable investment in research and thoughtful development.

In Poland, internal expenditure on research and development (R&D) activities in the biotechnology field in 2022 amounted to PLN 1,432.4 million and increased by 20.9% per year (Central Statistical Office, 2023). This amount is relatively small compared to the global

expenditure of approximately USD 600 billion (Biedrzycki, 2022). Polish biotechnology is still a relatively young discipline. Therefore, with the growing aspirations of Polish citizens and authorities, it is necessary to introduce practical strategies supporting progress and development.

The aim adopted by the authors in this article is to assess strategic partnership as a moderator of the Polish biotechnology industry's development and determine the factors shaping its effectiveness.

It was assumed that increasing investment budgets are optional for innovation development. Cooperation with the right partners can contribute to achieving much better results and thus to the development of the industry.

Strategic partnership may be underestimated in a turbulent reality; nonetheless, it impacts the improvement of management and overall progress in this sector of the Polish economy.

Based on the literature analysis, the concept of strategic partnership was formulated in the first part of the article, and its measurable benefits were indicated. Next, their importance for developing the Polish economy was analysed using the example of Polish enterprises in the biotechnology industry.

Based on pilot studies, the following were verified: different understandings of the concept of strategic partnership among experts in the biotechnology industry in Poland, which may hinder further potential cooperation, as well as factors shaping its effectiveness. An interview with a representative of the Association of Biotechnology Companies in Poland confirmed the need to expand partnerships to develop a cost-intensive industry with high technological and regulatory requirements.

The article ends with a summary in which the authors notice the potential of strategic partnerships, which constitute the nucleus of the innovation ecosystem, and indicate the determinants of effective partnerships. At the same time, they point out that the need for a register of enterprises' strategic cooperation initiatives makes their analysis difficult or even impossible.

2. Strategic partnerships

According to the literature, a partnership is a relationship between independent entities resulting from their entrepreneurial market attitude based on mutual trust, commitment and responsibility. The effects of their cooperation are to be lasting and provide a specific benefit (Stern et al., 2002).

The overriding motive of the partnership is to strive to reduce the level of total costs and increase the value of the partners involved in each relationship (Cygler, 2000; Sudolska, 2010). When this type of cooperation is long-term, it is called a strategic partnership. Achieving goals

through partnerships with other entities seems more accessible and safer (Sudolska, 2010). Strategic partnerships may be formed based on the aggregation of licensing, research and development (R&D), marketing, production, commercialisation, supply and distribution agreements.

In the 1970s, during the market domination of large global corporations with their research laboratories, team research was popularised, especially among emerging industries, i.e. biotechnology (Kopczyński, 2023). However, since the 1980s, the largest U.S. pharmaceutical companies have demonstrated dynamic capabilities by investing in external strategic partnerships with biotechnology entities (Schramm et al., 2022). The goal was to complement internal R&D capabilities by leveraging partners' biotechnology expertise and R&D efforts (Galambos, Sturchio, 1998). Strategic partnerships are a crucial element of building competitive advantage (Doz, Hamel, 1998), which was quickly noticed by the pharmaceutical industry.

An example could be a case study of Genentech (a biotechnology company) with Eli Lilly (a pharmaceutical company), which defended its position as the insulin leader in the American market in the 1980s and successfully entered the European market by introducing the first recombinant human insulin - Humulin.

The strategic partnership is based on risk sharing and aims to achieve common business goals and mutual benefits. The table below presents the benefits resulting from the collaboration in question.

Table 1.

Mutual benefits resulting from the strategic partnership on the example of Genentech and Eli Lilly

No.	Genentech benefits	Eli Lilly benefits
1.	Access to Eli Lilly's financial and production resources. Although Genetech had developed an innovative technology for insulin production, it needed to have the scale to commercialise its product quickly and effectively on a mass scale.	Technological advantage - among others, over Novo Nordisk, which was also developing its insulin production technology.
2.	Faster technology commercialisation. Eli Lilly's distribution channels, as well as contacts with doctors and medical institutions, shortened the time of product launch.	Increasing production safety and efficiency. Cheaper, more efficient production compared to obtaining insulin from animals.
3.	Consolidating its position in the biotechnology market (a young company gained the status of a biotechnology pioneer).	Recognition among doctors and patients (a product more similar to natural, human insulin).
4.	Profits from licenses allowed for further development of innovative drugs and technologies, such as oncology drugs or monoclonal antibodies, which brought considerable successes in the following decades.	Maintaining a dominant position on the insulin market and strengthening the global leadership in diabetes treatment.

Own study, Source: Miller, 2019; Kopczyński, 2023.

The license with Eli Lilly was more beneficial for Genentech than its commercialisation. The biotechnology company gained new experience from this cooperation, which was an investment in further innovative solutions. Today, it is a partner of the Roche group. As stated on its website (<https://www.gene.com/partners>):

Approximately half of Roche and Genentech products and medicines sold on the market result from successful cooperation with companies and institutions worldwide.

Eli Lilly and Genentech's strategic partnership not only marked a success for the companies but also demonstrated that regulatory agencies, such as the U.S. Food and Drug Administration, can adapt to breakthrough technologies, accelerating drug approval.

The foundation of strategic partnerships is building lasting and trust-based relationships. Trust is essential for effectively sharing knowledge, resources and responsibility (Jakubowski, 2024). Strategic partnerships provide access to external experiences, technologies and assets that expand the internal understanding of enterprises (Akram et al., 2020). A crucial element of strategic partnership is the mutual complementation of competencies. Therefore, when selecting partners, it is essential to determine how to match or complement internal research and development knowledge. Open communication and regular information exchange allow for monitoring progress and quick responses to possible problems.

The scope and complexity of partnerships vary. The more complex solutions companies need, the more often they seek specialist knowledge from various external partners (Ng, Sánchez-Aragon, 2024). Strategic partnerships can provide benefits, including access to new knowledge, reduced product development risk, and faster time to market for innovations (Liu et al., 2016). However, they can also contribute to generating losses. External spill-over effects are often presented as inputs independent of the company's research and development (Boeing, Hunerman, 2020; Martínez-Sánchez et al., 2020; Tung, Binh, 2022).

In today's dynamic market, the concept and description of strategic partnership will change according to its evolution. Therefore, it can be assumed that strategic partnership is still a poorly structured area of research and, consequently, very interesting for further analysis (Adamik, 2015). According to the article's authors, strategic partnership today is intertwined with other forms of cooperation, i.e. open innovation or cooperation networks, undoubtedly leading to the development of an innovation ecosystem.

In this article, strategic partnership is understood as a specific form of cooperation based on voluntary interdependence between two or more partners, the purpose of which is to share knowledge and resources with partners so that they bring benefits to all parties.

3. The essence of strategic partnerships in the biotechnology sector - biotechnology as a source of breakthrough innovations

Biotechnology is one of the most critical sectors of the knowledge-based economy, where the most dynamic increase in R&D expenditure is observed (Marszałek, 2022). The potential for biology-based solutions to social problems makes biotechnology one of this century's most promising technological areas.

Biotechnology is used in medicine (according to Niosi & McKelvey (2018). Six out of ten most frequently sold drugs are biotechnological products), agriculture, food, pharmaceutical and cosmetics industries. It can support various sectors of the economy and develop industries, but it can also be related to bioterrorism and address the issue of biological weapons.

The biotechnology industry, in which intellectual capital plays a key role, has become a driving force for dynamic changes in other sectors of the economy. Its dependence on the efficient implementation of innovations (Marszałek, 2022) may determine the success of strategic partnerships.

Biotechnology in Poland is one of the industries in which innovative activities are most often undertaken. Nevertheless, it must work on high research and development costs, limited commercialisation and constant technological changes. As a result, interest in external partnerships is growing (Runiewicz-Wardyn, 2020).

Research and development are the main factors in the development of many enterprises, which determine their competitiveness. According to the literature on the subject, an essential feature of the research and development process of enterprises is the law of diminishing returns (Leiponen, Helfat, 2010; Ravichandran et al., 2017; Boeing, Hunerman, 2020), which mainly large enterprises struggle. This law means that when we increase research and development budgets, we achieve a decrease in innovative productivity. This relationship was confirmed, among others, by a study by Graves & Langowitz in 1993, where increased investment decreased the discovery of new chemical entities. Scientists have noted the notable presence of this law in the case of mergers and acquisitions. Knott came to similar conclusions in 2017, stating that pharmaceutical companies like Pfizer can improve innovation performance by reducing research and development budgets by three billion dollars annually. The author proved that optimising resource allocation is the key to increasing productivity in R&D instead of just growing budgets.

Large companies are more prone to financial risk and bureaucracy, which challenge introducing creative ideas (Schumpeter, 1995). The antidote may be a strategic partnership with a smaller enterprise or start-up. Investment projects in biotechnology are of a long-term nature, so they are assumed to fit into the concept of strategic partnership (Doz, Hamel, 1998), which provides a good chance of success and the development of new, promising products or services.

For years, the United States has been a leader in developing and consolidating global biotechnology (Barcelos et al., 2018). In the European Union, strategic partnerships are in their infancy. The European Commission sees them as an opportunity to stimulate European biotechnology by proposing targeted actions (European Commission, 2024), i.e.:

- creation of large, regional partnerships for upskilling and change aimed at strengthening biotechnology skills;
- creation of regional innovation valleys aimed at supporting cooperation and synergy through the implementation of technologies related to biotechnological processes;
- launching international biotechnology partnerships with key global partners, i.e. the United States, India, Japan and South Korea.

Strategic partnerships played a significant role in the growth of the United States power in the 1980s. The E.U. is also focusing on its development in the biotechnology industry, drawing on the experience of a world leader. Biotechnology, with its intellectual capital and in combination with other economic sectors, has a chance to improve the quality of our lives in a turbulent world. A significant condition for their effectiveness is the proper selection of partners.

4. Strategic partnerships in Polish biotechnology enterprises

At a time when the E.U. is creating strategic partnerships for the development of the economy, biotechnology enterprises in Poland need help with obstacles in raising capital. The barriers are the need for proper communication of capital needs and the inappropriate way of presenting investment projects (Newseria Business, 2022). Many promising, innovative companies are looking for support abroad, taking advantage of the greater flexibility of investors there.

Noteworthy is the decline in cooperation of Polish enterprises with universities and public research institutions in favour of collaboration with other enterprises in the country and abroad (conclusion observed based on Central Statistical Office data for the years 2016-2018 and 2018-2020 regarding the cooperation of enterprises with selected entities, including universities, public research institutions, enterprises outside the own enterprise group, enterprises belonging to the own enterprise group), which may indicate a lack of trust in these potential partners.

In Poland, there has yet to be a list of concluded strategic partnerships despite detailed monitoring of R&D entities, which must submit a scientific and research potential assessment form to the Central Statistical Office once a year.

The effectiveness of strategic partnerships can be verified by the ability to generate profit from the cooperation concluded (commercialisation). Their efficacy is quickly noted in the industry press. For instance, out of 187 enterprises conducting biotechnology activities in

Poland (Central Statistical Office, 2023), only a few significant, successful initiatives were recorded in 2022, presented in Table 2.

Table 2.

Selected examples of effective partnerships in the biotechnology industry in Poland in 2022

Partnership		Partnership result	Description
Polpharma Biologics (P.L.)	Santo Holding (Strüngmann Group) (DE)	Biosimilar medicine	Bioeq CIMERLI™, a biosimilar drug to Lucentis®. It treats the wet form of age-related macular degeneration and other serious eye diseases.
Scope Fluidics (P.L.)	Bio-Rad Laboratories, Inc. (U.S.)	Commercialisation	Commercialization Curiosity Diagnostics Sp.z o.o.
Captor Therapeutics (P.L.)	Ono Pharmaceutical (JPN)	Cooperation agreement	Cooperation in developing small molecules capable of degrading a molecular target may be applicable primarily in neurodegenerative diseases, as agreed by both parties.
Ryvu Therapeutics (P.L.)	BioNTech (D.E.)	Cooperation agreement	Scientific agreement and agonist development STING.

Source: Biedrzycki, 2022.

Based on the data presented in Table 2, it can be seen that Polish biotechnology companies, although to a relatively small extent so far, are establishing partnerships with foreign entities. The reason for these initiatives is the partners' stable market position and the ability for them to co-finance costly research work. The cooperation mainly concerns the development of new products in the healthcare sector.

In Poland, the idea of strategic cooperation is just developing. The biotechnology sector is composed mainly of small and medium-sized enterprises (SMEs), which ideally meet the needs of complementing the specialist knowledge of entities from other sectors on a partnership basis. Strategic cooperation has been dominated by cooperation between biotechnology and pharmaceutical companies.

5. The concept and purpose of strategic partnership according to biotechnology industry experts - research method used and results

Due to the need for a clear definition of strategic partnership in the literature on the subject, the article's authors attempted to define this concept and establish its goal and factors shaping its effectiveness among representatives of the biotechnology industry in Poland. Therefore, in October 2024, a pilot study was conducted based on three face-to-face interviews. The respondents were randomly selected representatives of middle or senior management from various biotechnology enterprises in the SME sector in Poland (experts) who believe that strategic partnership significantly impacts the sector's development. The experts' answers are

presented in Table 3. A Likert scale from 1 (not very important) to 5 (very important) was used to assess the factors influencing the effectiveness of strategic partnerships. The respondents' answers were assigned to 5 groups with weights assigned to them, the sum of which is 100%.

The pilot study was supplemented with an interview with the President of the Association of Polish Biotechnology Companies on the current situation of strategic partnerships in the Polish biotechnology industry. The interview was conducted in October 2024.

Table 3.

Results of interviews conducted among employees of the biotechnology industry

No.	The concept of strategic partnership	The goal of strategic partnership	Is a strategic partnership with a university possible?	Factors shaping the effectiveness of cooperation (scale from 1 – not very important to 5 – very important)
1.	Synergistic cooperation is based on mutual trust, understanding the needs of the partners, and giving priority to partners to obtain mutual benefits. The party looking for a solution trusts the party, providing it that it will fully meet its needs by making its resources available. The ordering party consciously shares its resources and know-how to meet the other party's needs best.	Mutual benefits	Yes	Fulfilment of the goal assumptions (5); Transfer of knowledge and know-how between partners (5); Continuation of cooperation (3)
2.	Buying or selling products that generate significant revenues or provide the tools necessary to develop the business further.	Revenue, company development	Yes, but the university will only take such a partnership seriously if it is a nonprofit institution with financial benefits.	Trust (5), aligned goals to achieve the best results (5), flexibility in adapting to changing market conditions (4)
3.	An agreement between two parties, two entities with a common goal, idea and one account.	Project, product or portfolio development. Profit.	Yes	Trust (5); achieving the goal, beneficial to each party (4); commitment (4)

Own study based on interviews, October 2024.

Each respondent presented their definition of partnership, which includes a goal and aims to obtain benefits for all partners. However, the number of participants who can participate in such cooperation has yet to be specified. The duration of such a partnership was not defined either. In a follow-up interview, a period of long-term collaboration was agreed upon, during which universities could also participate. In this context, one of the respondents pointed out the need for more university involvement due to the divergence of goals. This remark may respond to the decline in interest in cooperation between enterprises and universities (ad. chapter 4). It was found that although the definitions of strategic partnership among sector representatives are diverse, the assumptions accompanying this definition are similar.

The responses regarding factors influencing the effectiveness of strategic partnerships were assigned as follows (see Table 4).

Table 4.

Factors shaping the effectiveness of strategic partnerships according to experts from the biotechnology industry in Poland

	Factor				
	Goal	Trust	Commitment	Adaptation to changing conditions	Continued cooperation
The sum of weights assigned by experts according to the Likert scale	14	10	9	4	3
Sum of weights	40				

Description: Purpose - understanding and achieving the goal. Commitment, including knowledge sharing.

Own study, based on interviews, October 2024.

According to the respondents, the same understanding of the goal and its achievement is the most critical factor determining the effectiveness of a given partnership (cooperation). This factor was indicated by 35% of study participants. The following factors are trust (25%) and commitment to collaboration, facilitating knowledge transfer and sharing know-how (22.5%). Other factors include adapting to changing market conditions (10%) and continued cooperation (7.5%). The factor responses are illustrated in Figure 1.

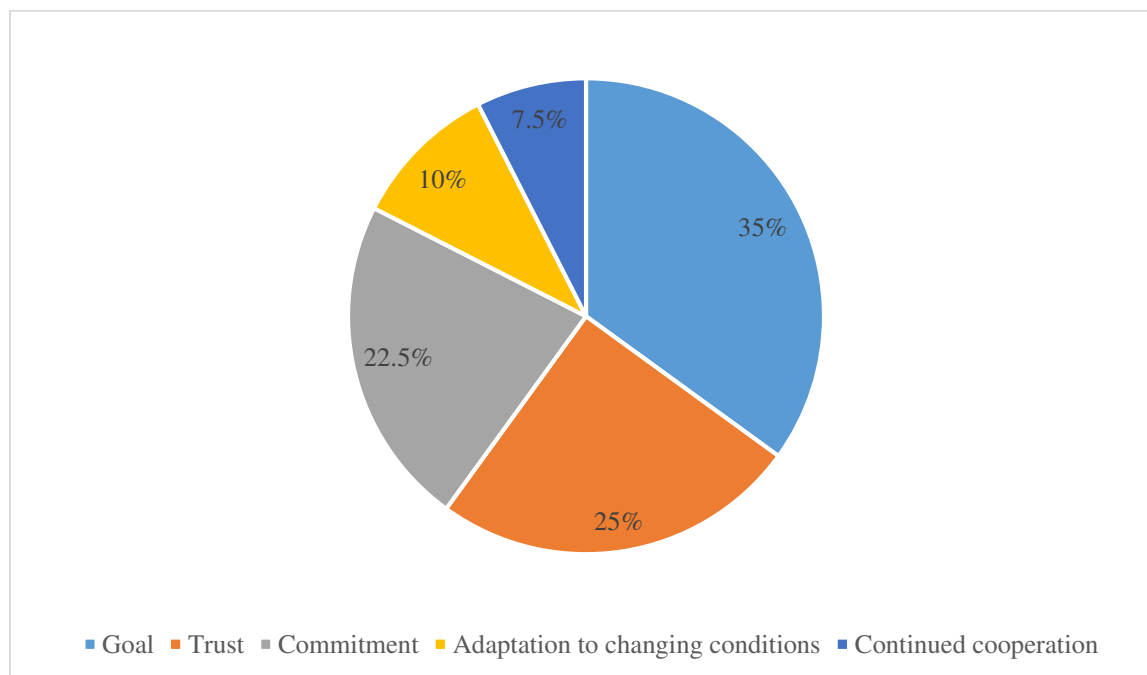


Figure 1. Factors shaping the effectiveness of cooperation in the biotechnology industry.

Own study, based on interviews, October 2024.

According to the President of the Association of Polish Biotechnology Companies, enterprises increasingly understand the essence and benefits of strategic partnership since it is an essential factor enabling them to keep up with technological development in Western economies. The pace of change and the high research costs encourage companies to cooperate

and share the costs and risks of developing an innovative solution. In the case of the Polish market, these are primarily bilateral partnerships concluded between enterprises or an enterprise and a university. Partnerships with more participants are created between universities or in international projects, such as in the case of projects from European programs or the Institute for Healthcare Improvement.

Moreover, in the President's opinion, strategic partnerships significantly impact the development of the biotechnology industry in Poland, which is very cost-intensive and has high technological and regulatory requirements. Hence, exchanging knowledge, experience, and resources is necessary to reduce the risk associated with developing innovative technologies.

6. Discussion

Creative, agile biotechnology companies from Poland are looking for partners internationally. The Polish biotechnology sector consists mainly of SMEs that require promotion and support in global markets. For this purpose, creating a Polish centre of biotechnology excellence would be invaluable.

In Poland, the idea of strategic cooperation is just developing. Currently, these are bilateral partnerships. Partnerships between biotechnology companies and entities from other industries should be launched, as there is a huge opportunity to obtain benefits in many areas of the economy through the synergistic use of their resources and competencies. It is worth introducing a register of strategic partnerships to monitor undertaken partnerships and assess their effectiveness.

The strategic partnership is an alternative to developing the biotechnology sector in Poland. However, it may remain unnoticed in the dynamic world of the interpenetration of many forms of cooperation and business models. It inevitably leads to the development of an innovation ecosystem.

Similar to the literature analysis, the pilot studies indicated the importance of trust, lasting relationships, and knowledge (also confirmed by the case study in Chapter 2) in strategic partnerships in biotechnology. Improving cooperation with universities using extensive teaching and research facilities may be crucial. In this situation, universities should be held accountable for their impact on the development of the Polish economy, in this case, on improving the biotechnology sector. Creating new forms of cooperation can only occur with significant support from institutional structures (Niosi, McKelvey, 2018). The achievement of the assumed goal is the main factor determining the effectiveness of a strategic partnership.

The Polish biotechnology sector needs strategic partnerships to integrate and strengthen cooperation between Polish companies and foreign partners to increase the credibility of Poland and domestic biotechnology internationally (Medexpress, 2024). The post-pandemic reality, which Cascio (2020) called the BANI acronym, defining the world as brittle, anxious, non-linear and incomprehensible, describes a situation which lacks ready-made action patterns and a simple answer to the question of how to manage the Polish biotechnology sector.

7. Summary

Based on the literature analysis, qualitative research and participant observations, the following conclusions have been formulated regarding strategic partnerships for the development of Polish biotechnology:

- There is no established, universally accepted definition of strategic partnership. The variety of its interpretations may make communication between potential partners easier.
- A strategic partnership is not only a partnership between enterprises but also the relations between enterprises and start-ups, universities, and public institutions. The potential of cooperation with universities and public institutions still needs to be used (Sieracka, Wirkus, 2022).
- The pharmaceutical sector dominates strategic cooperation with the biotechnology industry.
- The need to register strategic cooperation initiatives among enterprises makes their analysis difficult. It is worth considering changes to the current data collection system by the Central Statistical Office (complete study).
- Polish biotechnology enterprises are mainly entities from the SME sector, characterised by high creativity. They can complement the expert knowledge of entities from other industries and international corporations as part of strategic partnerships.
- Strategic partnership reduces the risks associated with the development of innovative technologies.
- Imitating American strategic partnerships in Poland may be impossible due to the lack of similar concerns capable of carrying out R&D.
- Polish strategic partnerships are concluded mainly with foreign entities.
- It is worth promoting Polish strategic partnerships globally with the government's support.
- Trust and commitment leading to the achievement of the assumed goal of the strategic partnership are the main factors determining its effectiveness.

The strategic partnership in the biotechnology sector in Poland is still a new phenomenon. It is often combined with other forms of cooperation in this area. It has yet to become an industry moderator, which constitutes a challenging field for further research. It is the nucleus of an innovation ecosystem that should undoubtedly be developed. Additionally, international partnerships should be established with the support of state authorities.

References

1. Adamik, A. (2015). Partnerstwo strategiczne a konkurencyjność przedsiębiorstw. Perspektywa MSP. *Zeszyty Naukowe, No. 1199, Rozprawy Naukowe*. Wydawnictwo Politechniki Łódzkiej.
2. Akram, M.U., Ghosh, K., Joseph, R.P. (2020). External Knowledge Sourcing and Innovation in Family Firms: How and Why Absorptive Capacity and Family Social Capital Matter. *Journal of Knowledge Management lub Journal of Information and Knowledge Management Systems, 51(3)*.
3. Barcelos, M., Fernanda, B. Lupki, F., Campolina, G., Nelson, D., Molina, G. (2018). The Colors of Biotechnology: General Overview and Developments of White, Green and Blue Areas. *FEMS Microbiology Letters*.
4. Biedrzycki, P. (2022). 6 najważniejszych wydarzeń w polskiej biotechnologii 2022 roku. Strefa Inwestorów Strefa inwestorów – Biotechnologia.
5. Biedrzycki, P. (2022). Polska biotechnologia jest wciąż na wczesnym etapie rozwoju i najlepsze ma przed sobą. BIOTECH DAY na GPW. Strefa Inwestorów - Wydarzenia.
6. Böing, P., Hünermund, P. (2020). *More R&D, Less Growth? China's Decreasing Research Productivity in International Comparison*. Department of Strategy and Innovation Zentrum für Europäische Wirtschaftsforschung.
7. Cascio, J. (2020). *Facing the Age of Chaos*, <https://medium.com/@cascio/facing-the-age-of-chaos-b00687b1f51d>
8. Chandler, A.D. (1977). *The Visible Hand: The Managerial Revolution in American Business*. Harvard University Press.
9. Cygler, J. (2000). Alianse strategiczne w ujęciu teorii kosztów transakcyjnych. *Przegląd organizacji No. 1*.
10. Czechowska, L. (2013). The Concept of Strategic Partnership as an input in the modern alliance theory. *The Copernicus Journal of Political Studies, No. 2(4)*.
11. Doz, Y., Hamel, G. (2001). Alliance Advantage: The Art of Creating Value Through Partnering. *Supply Chain Management, Vol. 6, No. 5*.
12. European Commission (2024). *Communication from the commission to the european parliament, the council, the european economic and social committee and the committee of*

- the regions. Building the future with nature: Boosting Biotechnology and Biomanufacturing in the E.U.* Brussels.
13. Galambos, L., Sturchio, J.L. (1998). Pharmaceutical firms and the transition to biotechnology: A study in strategic innovation. *Business History Review* Vol. 72.
 14. Główny Urząd Statystyczny (GUS) lata: 2023; 2016-2018 i 2018-2020.
 15. Graves, S.B., Langowitz, N.S. (1996). R&D Productivity: A Global Multi-Industry Comparison. *Technological Forecasting and Social Change*, Vol. 53, Iss. 2.
 16. Grudowski, P., Muchlado, M. (2023). *Czynniki kształtujące skuteczność outsourcingu w podmiotach leczniczych*. Wyd. Politechnika Gdańska.
 17. Jakubowski, K. (2024). *Partnerstwa strategiczne: Współpraca jako element strategii biznesowej*, <https://sprytneinwestowanie.pl/porady/partnerstwa-strategiczne-wspolpraca-jako-element-strategii-biznesowej/>
 18. Knott, A.M. (2017). *How Innovation Really Works: Using the Trillion-Dollar R&D Fix to Drive Growth*. McGraw Hill.
 19. Kopczyński, M. (2023). Insulina i upadek wieży z kości słoniowej. Rzecz o zmieniających się uwarunkowaniach innowacyjności. *Przegląd historyczny, Tom CXIV, Zeszyt 3*.
 20. Leiponen, A., Helfat, C.E. (2009). Innovation objectives, knowledge sources, and the benefits of breadth. *Strategic Management Journal*.
 21. Liu, Y., Sarala, R.M., Xing, Y., Cooper, C.L. (2017). Human Side of Collaborative Partnerships: A Microfoundational Perspective. *Group and Organization Management*, 42(2).
 22. Marszałek, A. (2022). Innowacje w sektorze biotechnologii jako katalizator procesu transferu wiedzy i technologii. *Kwartalnik Nauk o Przedsiębiorstwie, tom 65, nr 3*, SGH.
 23. Martínez-Sánchez, A., Vicente-Oliva, S., Pérez-Pérez, M. (2020). The relationship between R&D, the absorptive capacity of knowledge, human resource flexibility and innovation: Mediator effects on industrial firms. *Journal of Business Research*, Vol. 118.
 24. Medexpress (2024). <https://www.medexpress.pl/leki-technologie-medyczne/firmy-biotechnologiczne-wybraly-nowy-zarząd-branzowego-związku-bioforum/>
 25. Miller, H. (2019). *Record-Time FDA Approval of Human Insulin In 1982: When Genetic Engineering Came of Age*. American Council on Science and Health.
 26. Newseria Biznes (2022). *Polskie firmy nie umieją efektywnie komunikować się z inwestorami. W efekcie mają problemy z dostępem do kapitału na rozwój*, <https://biznes.newseria.pl/news/polskie-firmy-nie-umieja,p1813127079>
 27. Ng, D., Sánchez-Aragon, L. (2024). *How much is enough? The role of R&D investment in the innovation process*. Wiley.
 28. Niosi, J., McKelvey, M. (2018). *Relating Business Model Innovations and Innovation Cascades: The Case of Biotechnology, Business Model Innovation: New Frontiers and Challenges*. Oxford University Press.

29. Ravichandran, T., Han, S., Sunilem Mithas, S. (2017). Mitigating Diminishing Returns to R&D: The Role of Information Technology in Innovation, *Information Systems Research. Informis, Vol. 28(4)*.
30. Rifkin, J. (1999). The Biotech Century. *Journal of Technology Education, Vol. 10, No. 2*. New York, NY: Penguin Putnam.
31. Rothaermel, F.T. (2001). Complementary assets, strategic alliances, and the incumbent's advantage: an empirical study of industry and firm effects in the biopharmaceutical industry. *Research Policy, Vol. 30, Iss. 8*.
32. Runiewicz-Wardyn, M. (2020). W kierunku otwartych ekosystemów innowacji w Polsce: szanse i wyzwania. *Kwartalnik Nauk o Przedsiębiorstwie, 55(2)*.
33. Schramm, M.E., Place, K.R., Laskin, A.V. (2022). Framing the strategic R&D paradigm shift in Big Pharma: a content analysis of pharmaceutical annual reports. *Journal of Communication Management*.
34. Schumpeter, J. (2009). Kapitalizm socjalizm demokracja (Capitalism, Socialism and Democracy). New York: PWN, 1942.
35. Sieracka, W. (2022). Conditioning factors of the industry – Conditioning factors of Industry-University cooperation from the perspective of enterprises. *Scientific papers of the Silesian University of Technology, Organization and Management Series, No. 163*.
36. Stern, L.W., El-Ansary, A.I., Coughlan, A.T. (2002). *Kanały marketingowe*. Warszawa: PWN.
37. Sudolska, A. (2010). Partnerstwo przedsiębiorstw jako czynnik rozwoju ich kompetencji strategicznych. *Prace naukowe UE we Wrocławiu, no. 116*.
38. Tung, L.T., Binh, Q.M. (2022). The impact of R&D expenditure on firm performance in emerging markets: evidence from the Vietnamese listed companies. *Asian Journal of Technology Innovation, Vol. 30(2)*.

KEY FACTORS INFLUENCING COOPERATION IN A NETWORKED ORGANIZATION

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Purpose: This article aims to use the experience gained from implementing projects implemented in network structures to indicate key areas that influence the effectiveness of the undertaken cooperation, understood as the completion of the project by the project assumptions.

Design/methodology/approach: An interview study was conducted with the participation of 46 surveyed participants of projects implemented in the last 3 years. Each project was of a network nature, i.e. at least 2 independent organizations cooperated in its implementation.

Findings: The aim of this work is to verify the research hypothesis, which states that both cooperation and competition between teams have a significant impact on the quality of projects implemented within network structures.

Research limitations/implications: The sample is limited in size - the survey was completed by only 47 people participating in 14 projects with a national scope.

Originality/value: The article is unique because it presents practitioners' views of different environments (academic, business, public administration). The study is contributory, but it is planned to expand the survey and use it on a larger scale, enabling the construction of a universal model. The conclusions from the study can also be used to plan the course of further cooperation in network structures.

Keywords: cooperation in network structures, cooperation and competition model, cooperation, cross-functional cooperation.

Category of the paper: Research Paper.

1. Introduction

The article aims to verify the research hypothesis, which states that cooperation between teams significantly impacts the assessment of the implemented project. The fact that the project was implemented according to the initial plan and assumptions without excessively exceeding the budget, time, and resources is a measurable criterion for project assessment. In the conditions of the network economy, we are dealing with the need to constantly undertake cooperation activities, very often going beyond the traditional boundaries of a single enterprise

or institution. This results from limitations in all kinds of material and non-material resources. An organization's market position often depends on the success of implementing projects, and sometimes, it is a factor decisive for its survival in the market. At the same time, the "portfolio" of successes is a networking factor. This means that the organization develops a reasonable opinion and reputation as a reliable and valuable partner for cooperation. This can be another essential element in building the organization's market position. This article aims to use the experience from the cooperation carried out in the last 3 years in 14 projects of national scope in Poland, where each project was carried out in the conditions of network cooperation. Each project was carried out in cooperation with at least two independent organizations. The study aims to determine the impact of competition for material and non-material resources and cooperative behaviors among cooperation members representing different institutions on assessing the implementation of the undertaken cooperation activities and satisfaction with this cooperation.

2. Cooperation in network structures

Any organizational activity aimed at achieving predetermined goals requires the involvement of resources. As the scope of actions undertaken and the complexity of tasks increased, these resources must become increasingly diverse, and sometimes access to them is highly limited. Undertaking new actions requires the organization to make decisions regarding its relations with the environment. The ability to create competitive advantages is a factor that largely determines the organization's future actions and affects its attractiveness to other market participants. These competitive advantages are built based on resources owned by the company or used by it. Traditionally, company resources are divided into two categories: tangible and intangible. Tangible resources include fixed assets, real estate, machines, raw materials, and financial resources. Intangible resources consist of various procedures, operating models, know-how, patents held, and the human factor - employees and their experience, knowledge, and skills. The classic definition of a resource says it must be valuable, rare, and difficult to copy and replace. M. Dollinger (2002, pp. 43-54) lists six types of strategic resources of a company (PROFIT formula): physical, reputational, organizational, financial, intellectual, human, and technological. Discussions on global competitive advantages resulting from effectively combining national circumstances with the company's strategy are becoming more frequent (Porter, 1985). Even a company's operational excellence, which results in a leadership position, cannot guarantee success in a new market. Available resources are one of the pillars of strategy; the other is the organization's environment. In the case of business organizations, we usually talk about a competitive (market) environment in which the customer has the opportunity to choose a supplier. In such a situation, the position can be extended to new

markets and segments, and the actual market power can be strengthened by finding a business partner. Another form may be a situation where a current competitor transforms into a partner with whom we undertake joint actions for a certain period. In such situations, we often talk about competition (Cygler, 2009, pp. 22-27). It is an indirect relationship involving simultaneous cooperation and competition (Czakoń, 2009).

Collaborative activities are increasingly undertaken in the form of networks. This is a result of the development of the ICT network and a natural consequence of the increasingly widespread use of ICT tools in the daily operations of organizations. Undertaking collaborative activities through networks allows organizations to use their partners' knowledge, skills, and competencies. It is an opportunity for organizations to build or strengthen their market position. An essential role in network systems is played by IT systems that support the processes of creating new models of work, communication, and cooperation. As a result, the emergence of various organizational networks in the form of "extended organizations" can be observed more and more often (Mircea et al., 2016; Marchetti, 2023). These structures are intensely focused on sharing, exchanging, and creating knowledge, skills, and competencies, so they are often a place where innovative solutions are created. A network is a model or metaphor describing a system of connections between specific entities. While in social relations, this number can be huge (which can be observed in the form of social networking sites), in economic relations, this number is usually clearly defined. These connections include (Yin, Shanley, 2008; Aulkemeier, 2019):

- trust and interoperability,
- connections and interactions between entities that are part of the network, where the concept of connections means long-term relationships, while interactions are short-term relationships,
- structure and position are understood as the interdependence of the elements that make up the network and - as a result - how their mutual relations are shaped,
- process is a change in company ties due to jointly implemented tasks.

The importance of informal connections in a network organization is emphasized by authors for whom a network organization is, to a much greater extent, the effect of combining informal networks and goals (tasks that members of the network organization want to accomplish) than formal structures (Czakoń, 2019; Kisielnicki, Sobolewska, 2021; Bayiere et al., 2019). W. Sroka (2010) emphasizes this fact by noting that an organization can only be considered a network when it does not fit within the boundaries set by the formal structure. Organizations cooperating within a network organization choose various connections: strategic alliances, clusters, or cooperative relations. The primary goal of each of these organizational forms is to achieve goals that would be unattainable for an organization operating alone.

Regardless of the form of cooperation undertaken, we can indicate certain factors that influence the willingness to cooperate between organizations. These are:

- leadership and culture of cooperation: effective leadership and a culture promoting cooperation are vital to increasing the performance of the organization (Sepuru et al., 2021),
- characteristics and compatibility of cooperating partners have a significant impact on the success of joint efforts (Feller et al., 2009),
- trust and interoperability: trust between partners and interoperability of IT systems are essential to managing the success of cooperation,
- strategic and external factors: external influences and strategic alignment also promote successful cooperation (Gruat La Forme et al., 2007; Saiz et al., 2010).

J. Cygler (2009) makes a similar distinction. It indicates that entering into cooperation relations is a derivative of two groups of factors:

- internal, resulting from the specificity of the organization itself, the management method, goals, and strategies, as well as the organizational culture in force in,
- sectoral – such as technological advancement, the sector's structure, its profitability, or entry barriers.

However, regardless of the sector and the specificity of the organization itself, the directions of development (and the pace of changes taking place in the market) require the organization to be ready to undertake various activities, including cooperation activities.

All these cooperation activities aim to increase the organization's efficiency using the synergy effect. In the organization, cooperation facilitates the transfer of resources, including knowledge resources, which should ultimately increase the organization's innovative capabilities (Wohlin et al., 2012).

3. Own study

The research used the model proposed and verified by S. Ghobadi and J. D'Ambra (2012). The original model describes cooperation within functional task teams; the author aimed to study project knowledge and the factors influencing it. A similar study, focusing on strictly scientific projects, was conducted in 2017. In the current study, I used proven constructs and the model (Pronskikh, Sobolewska, 2018). Similar to the model described in this article, the author of the 2012 study focused on the implementation of projects of cross-functional organizations that were geographically dispersed.

The research assumes that the final effect of cooperation is a derivative of cross-functional cooperation of independent units.

The first research task is to identify factors influencing the relations of cross-functional cooperation in scientific projects. The aim of the study is not only to identify factors influencing cooperation relations but also to determine the nature of their impact. The second research task identifies factors influencing competitive relations between entities in projects implemented in network cooperation conditions. In particular, I would like to obtain an answer to the question of which factors (material or non-material) and how they influence the competitive relations between cooperating entities.

The study, the results of which will be presented in this article, was conducted through a dedicated website containing questions (CAWI) was conducted in August 2024 and was addressed to a non-random group. Fifty-three respondents who had participated in implementing a project in a network structure (i.e., in cooperation between different organizations) in the last 3 years were invited to the study. The study involved people representing 14 projects with a national scope (Poland). As a result of the study, obtaining 47 fully completed surveys was possible. The survey contained 14 primary questions and four additional ones, in which information about the respondents was requested: their place of employment, position in the project, gender, and age (Table 1).

Table 1.
Survey metrics

Sex	N	%
Female	28	60,9%
Male	18	39,1%
Age	N	%
Less than 30	8	17,4%
30-40	10	21,7%
40-55	16	34,8%
55+	8	17,4%
Refusal to answer	4	8,7%
Role in the project	N	%
Team member	25	54,3%
Task/project leader	21	45,7%
Affiliation	N	%
university	7	15,2%
business	24	52,2%
Public administration	11	23,9%
NGO	4	8,7%

Source: own work.

The model uses three constructs: quality of cooperation is assessed in the category of project success. To assess success, the classic project approach was used, which is presented as a project triangle (scope, time, and project quality consistent with the assumptions established before the start of cooperation activities). Quality of cooperation is understood here as the degree of fulfillment of project requirements. Cooperation between project participants takes place on three levels: cooperation in implementing tasks (task orientation), interpersonal relations, and communication. Competition is the degree to which project participants tend to compete. Competition is expected in every implemented project, regardless of the specificity of the undertaking. Competition is a natural consequence of coping with objective limitations

in access to project resources. All these constructs are reflected in the research questions (Table 2). As part of the survey, participants were to answer questions about their activities and experiences resulting from cooperation using a 5-point Likert scale. Basic statistical measures for the sample of 46 responses are presented in Table 3.

Table 2.
Survey structure

Construct	Questions
Project Qualification Assessment (CQ)	The jointly implemented project was completed by the fundamental assumptions (time/scope/quality)
Assessment of Collaboration Between Teams (CFUN)	Collaboration's assessment
Task Orientation (TASK)	1. Other teams completed their work according to established schedules and without unnecessary delays or obstacles (TASK1) 2. The participation of all other collaborators in the experiments is essential to the overall success of the project (TASK2) 3. There were no problems resulting from task planning, defining the scope of responsibilities of individual teams, and task schedules (TASK3)
Communication (COMM)	1. Information and knowledge resources provided as part of the project implementation served to achieve the goals (COMM1) 2. Both the goals of individual tasks and current results as part of the project implementation were systematically published and discussed by cooperating teams (COMM2) 3. Problems arising as part of the project were discussed and solved on an ongoing basis (COMM3) 4. As part of the project implementation, collaborators declared their willingness to cooperate and mutual readiness to assist other participants (COMM4)
Interpersonal relationships (IREL)	1. Collaborators communicated regularly with other partners, not limited to scheduled statutory meetings (IREL1) 2. Collaborators established social relationships outside of the workplace (IREL2)
Competition within the project (RIV)	The intensity of competition during the project implementation
Competition for Material Resources (TGBR)	1. Competition for resources necessary to implement the project (tools, software, etc.) (TGBR1) 2. Competition for financial resources (TGBR2)
Competition for Intangible Resources (TGBR)	1. Competition for the attention and support of the project management (ITGBR1) 2. Resulting from the need to promote the employer (the entity employing the employee) and highlight its contribution to the project implementation (ITGBR2)

Source: own work.

Table 3.
Basic descriptive statistics for the sample N = 46

Construct	Average	Standard Deviation	Variance
Project Qualification Assessment (CQ)	4,24	0,85	0,67
Assessment of Collaboration Between Teams (CFUN)	4,11	0,77	0,59
Task Orientation (TASK)	3,72	0,71	0,50
Communication (COMM)	4,00	0,54	0,29
Interpersonal relationships (IREL)	3,85	0,71	0,51
Competition within the project (RIV)	3,78	0,92	0,84
Competition for Material Resources (TGBR)	3,89	0,79	0,62
Competition for Intangible Resources (TGBR)	3,96	0,74	0,55

Source: own work.

Table 4 illustrates the correlation between the analyzed factors. A strong correlation is one for which the quotient is more significant than 0.5. Such a correlation indicates a functional relationship between the analyzed factors. The table highlights factors with moderate (greater than 0.3) or significant correlation coefficients.

Table 4.

Correlation analysis (N = 46) with strong and moderate correlation coefficients marked title

	CQ	CFUN	TASK	COMM	IREL	RIV	TGBR	ITGBR
CQ	1							
CFUN	0,77	1						
TASK	0,37	0,29	1					
COMM	0,62	0,37	0,14	1				
IREL	0,01	0,11	0,16	0,084	1			
RIV	0,10	0,19	0,54	-0,04	0,24	1		
TGBR	0,21	0,11	0,34	-0,01	0,28	0,51	1	
ITGBR	0,42	0,48	0,22	0,24	0,04	0,20	0,37	1

Source: own work.

The analysis presented in Table 4 indicates that the assessment of the project and the quality of its implementation are most strongly influenced by factors responsible for cooperation in the implementation of tasks and aspects related to communication within the project. It should be noted that the existence of a correlation between factors does not mean causality. It can be seen that there is a strong connection between the assessment of the project quality and the assessment of commitment to the implementation of tasks and, similarly, this connection is much smaller in the case of the assessment of the project and the assessment of interpersonal and social relations that took place at the time when the cooperation relationship was established.

In order to verify the hypothesis stated in the introduction to the article, I used a linear regression model (Table 5). For the adopted model, the value of the R-squared ratio was 0.79, which means that the model explains as much as 79% of the variability of the dependent variable (i.e., in the case of the model for assessing the quality of cooperation).

Table 5.

Regression analysis for model (N = 46)

Regression statistics				
R-multiple	0,893299384			
R-squared	0,79798379			
Fitted R-squared	0,760770278			
Standard error	0,401809868			
Observations	46			
Variance analysis				
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>
Regression	7	24,24	3,46	21,44
Residual	38	6,14	0,16	
Total	45	30,37		

Cont. table 5.

	Coefficients	Standard Dev.	t Stat	p-Value
Intersection	-1,10	0,61	-1,81	0,08
CFUN	0,66	0,11	6,86	3,77
TASK	0,23	0,11	2,22	0,03
COMM	0,58	0,12	4,79	2,55
IREL	0,17	0,09	-1,86	0,07
RIV	0,17	0,09	-1,91	0,06
TGBR	0,24	0,10	2,49	0,02
ITGBR	0,06	0,11	-0,62	0,54

Source: own analysis.

The regression analysis method was also used to determine the factors influencing the cooperation and competition relationships. The results are presented in Figure 1.

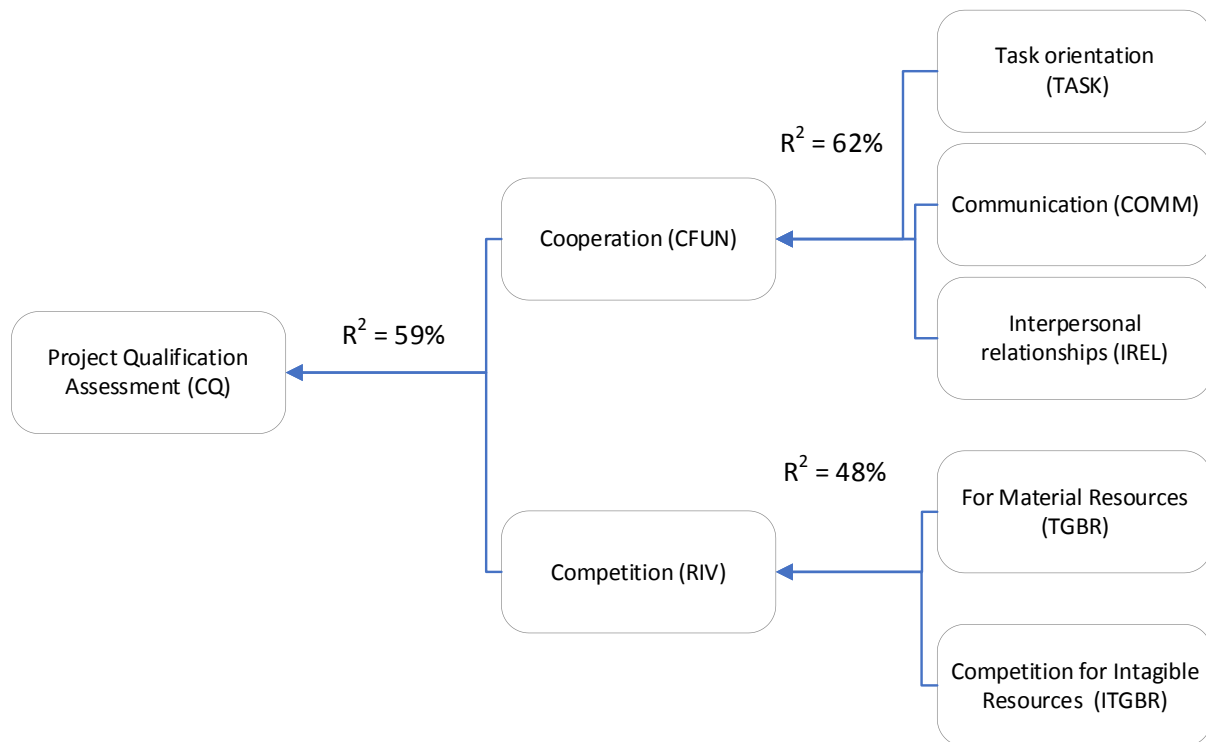


Figure 1. Results of regression analysis for three models.

Analyzing the first component model (Fig. 2), i.e. analyzing determinants of cooperation, after rejecting factors with insignificant statistical significance ($p < 0.05$), it can be seen that the success factors were practical cooperation, by the established plan, schedule and division of tasks within the cooperation project (TASK1), as well as a genuine desire to implement the project manifested in responding to emerging problems and providing assistance (COMM4), and solving them when the problem arose (COMM3). An essential element was also the fact that cooperation participants in network conditions desired to establish social relationships beyond their workplace (IREL2). This refers to lasting contacts or acquaintances in a private life sphere. This factor is related to cooperative interpersonal relations in project management.

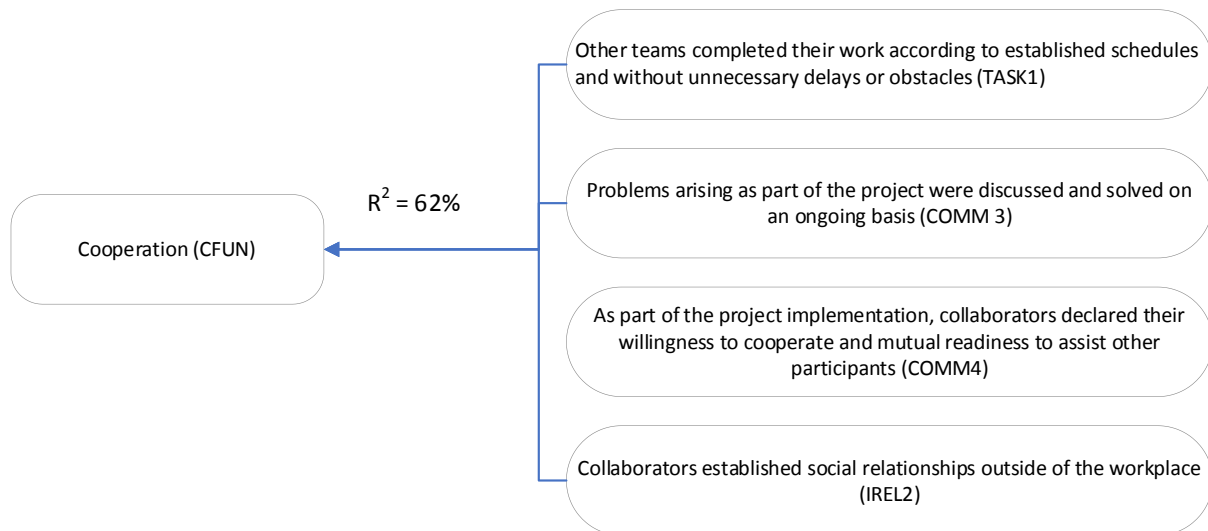


Figure 2. Results of regression analysis for the model describing determinants of cooperation (after rejecting factors $p < 0.05$).

In the area of rivalry, the factors that positively influenced competitive relations were those related to competition and limitations resulting from limited access to material resources. Usually, this concerns access to tools or software necessary for project implementation (TGBR1) and competition for intangible resources. In particular, this concerned emphasizing the parent unit's distinctiveness and contribution to the project's implementation (ITGBR2) (Fig. 3).

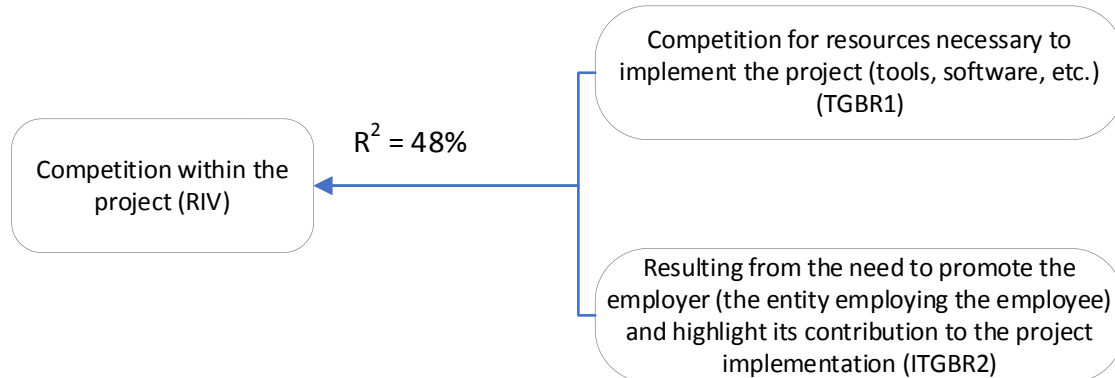


Figure 3. Results of regression analysis for the model describing determinants of competition (after rejecting factors $p < 0.05$).

The growing complexity of all types of projects and the simultaneous limited access to material and intangible resources force the creation of partnerships and undertaking cooperation activities. Such cooperation often goes beyond organizational boundaries and functional dependencies. Sometimes, we are dealing with a situation of undertaking joint actions by entities competing with each other in everyday market conditions. The conducted study, the undoubted limitation of which is the sample size, shows a significant regularity. It indicates several determinants that directly impact the assessment of the quality of the implemented cooperation/project. This is an essential issue because reputation and good cooperation experiences can result in further, jointly undertaken challenges. Some of the factors directly

influencing the assessment of cooperation are deterministic. This means the processes are predictable and can be identified with high probability at the project planning stage. These are strictly organizational factors related to the material resources of the analyzed projects. A much more exciting group of factors strongly influencing the evaluation of cooperation and the project's outcome are non-deterministic factors. These are factors related to the intangible assets of the project, mainly the human factor. There are various types of relationships between members of the research team. These are both cooperation and competition relationships. They should be the subject of monitoring and prudent management to further cooperation in network structures.

4. Summary

This work aims to verify the research hypothesis that cooperation and competition between teams significantly impact the quality of scientific projects. The aim was to research the nature of factors influencing cooperation relations. The research task was to analyze the factors facilitating cooperation and competition in projects implemented in network cooperation conditions.

The analyses indicated several factors that positively impact the quality of the project being implemented and, consequently, the willingness to continue joint activities. Both acts of cooperation and competition are inseparable elements of every undertaken project. However, the study shows that good project planning and systematic implementation of its assumptions are necessary for the success of the entire undertaking. Maintaining constant vigilance, monitoring the course, and detecting irregularities at the earliest possible stage is equally important. In such situations, the factor that positively impacts the project assessment is the ability to communicate between dispersed teams and the willingness to solve problems together. Because people and organizations with different levels of advancement and experience cooperate in the implementation of projects, a precious element is the willingness to cooperate, share knowledge, act as a mentor, and be ready to engage in discussions. Another valuable element is the openness to establishing non-professional relationships between members of project teams. In terms of competition, it is impossible not to notice the need to compete for material resources, which may also include funds allocated to implement the project. An exciting factor from the research is the need to self-promote one's unit. This is also wholly justified because within the framework of a jointly implemented project, individual contribution often disappears, and we began our considerations with a note on the need to build one's brand and a "portfolio of successes".

References

1. Aulkemeier, F., Iacob, M.-E., van Hillegersberg, J. (2019). Platform-based collaboration in digital ecosystems. *Electronic Markets*, Vol. 29, Iss. 4, pp. 597-608, doi: 10.1007/s12525-019-00341-2
2. Baiyere, A., Salmela, H., Tapanainen, T. (2020). Digital transformation and the new logics of business process management. *European Journal of Information Systems*, Vol. 29(3), pp. 238-259, doi: 10.1080/0960085X.2020.1718007
3. Baretta, A. (2008). The functioning of co-opetition in the health-care sector: An explorative analysis. *Scandinavian Journal of Management*, Vol. 24, Iss. 3, pp. 209-220, doi: 10.1016/j.scaman.2008.03.005
4. Bartkowiak, P., Koszel, M. (2015). Koopetycja jednostek samorządu terytorialnego, *Przegląd Organizacji*, Vol. 9, pp. 59-76, doi: 10.33141/po.2015.09.10
5. Bengtsson, M., Kock, S. (2000). Coopetition in Business Networks: To Cooperate and Compete Simultaneously. *Industrial Marketing Management*, Vol 29, pp 411-426, doi: 10.1016/S0019-8501(99)00067-X
6. Cygler, J. (2009). *Kooperencja przedsiębiorstw. Czynniki sektorowe i korporacyjne*, Warszawa: Oficyna Wydawnicza SGH.
7. Cygler, J., Romanowska, M. (2014). *Granice zarządzania*. Warszawa: Oficyna Wydawnicza SGH.
8. Czakon, W. (2009). Koopetycja – splot tworzenia i zawłaszczania własności. *Przegląd Organizacji*, Vol. 12, pp. 11-14, doi: 10.33141/po.2009.12.03
9. Dollinger, M. (2002). *Entrepreneurship: strategies and resources*. New York: Prentice Hall.
10. Feller, J., Finnegan, P., Hayes, J., O'Reilly, P. (2009). Institutionalising information asymmetry: governance structures for open innovation. *Information Technology & People*, Vol. 22, No. 4, pp. 297-316, doi: 10.1108/09593840911002423
11. Ghobadi, S., D'Ambra, J. (2012). Knowledge sharing in cross-functional teams: a cooperative model, *Journal of Knowledge Management*, Vol. 16, Iss. 2, pp. 285-301, doi: 10.1108/13673271211218889
12. Gnyawali, D.R., Park, B.J. (2011). Co-opetition between Giants: Drivers and Consequences of Collaboration between Large Competitors. *Research Policy*, Vol. 40(5), pp. 650-663, doi: 10.1016/j.respol.2011.01.009
13. Gruat La Forme, F.-A., Genoulaz, V.B., Campagne, J.-P. (2007). A framework to analyze collaborative performance. *Computers in Industry*, Vol. 58(7), pp. 687-697, doi: 10.1016/j.compind.2007.05.007
14. Marchetti, E., Nikghadam-Hojjati, S., Barata, J. (2023). Collaborative Network 5.0: By Design Human Values and Human-Centred Based Extended Collaborative Networks.

- In: L.M. Camarinha-Matos, X. Boucher, A. Ortiz (Eds.), *Collaborative Networks in Digitalization and Society 5.0. PRO-VE 2023. IFIP Advances in Information and Communication Technology*. Cham: Springer.
15. Merrifield, D.B. (2007). Strategic Collaborations – Essence of Survival. *Research Technology Management*, No. 50(2), doi: 10.1080/08956308.2007.11657424
 16. Mircea, M., Ghilic-Micu, B., Stoica, M., Sinioros, P. (2016). Inter-organizational performance and business process management in collaborative networks. *Economic Computation and Economic Cybernetics Studies and Research*, Vol. 50(2), pp. 107-122, Retrieved from: <https://ideas.repec.org/a/cys/ecocyb/v50y2016i2p107-122.html>, 23.06.2023.
 17. Porter, M.E. (1985). *The Competitive Advantage of Nations*. New York: Free Press.
 18. Pronskikh, V., Sobolewska, O. (2018). Coopetition model of knowledge sharing in science: an eastern-european case study. *Acta Physica B Proceedings Supplement*, Iss. 4 Vol. 11, pp. 803-82, doi: 10.5506/APhysPolBSupp.11.803
 19. Saiz, J.J.A., Rodriguez, R.R., Bas, A.O., Verdecho, M.J. (2010). An information architecture for a performance management framework by collaborating SMEs. *Computers in Industry*, Vol. 61(7), pp. 676-685, doi: 10.1016/j.compind.2010.03.012
 20. Sepuru, M., Musonda, I., Okoro, Ch. (2021). *An Assessment of Factors Influencing Collaboration Impacts on Organisational Performance: A Review. Collaboration and Integration in Construction, Engineering, Management and Technology*, doi: 10.1007/978-3-030-48465-1_54
 21. Sobolewska, O. (2016). Kooperencja w ujęciu współczesnych realiów współpracy strategicznej. *Studia Ekonomiczne. Zeszyty Naukowe Uniwersytetu Ekonomicznego w Katowicach*, No. 283, pp. 121-132.
 22. Sroka, W. (2010). Korzyści i zagrożenia uczestnictwa w sieci aliansów – analiza porównawcza. *Przegląd Organizacji*, No. 1, pp. 28-31, doi: 10.33141/po.2012.01.07
 23. Wohlin C., Aurum, A., Angelis, L., Phillips, L., Dittrich, Y., Gorschek, T., Grah, H., Henningsson, K., Kågström, S., Low, G., Rovegard, P., Tomaszewski, P., Van Toorn, C., Winter, J. (2012). The success factors powering industry-academia collaboration. *IEEE Software*, Vol. 29(2), pp. 67-73, doi: 10.1109/MS.2011.92
 24. Yin, X., Shanley, M. (2008). Industry determinants of the “Merger Versus Alliance” Decision. *Academy of Management Review*, Vol. 33, No. 2, 473-491. Retrieved from: <http://www.jstor.org/stable/20159408>, 12.08.2024.
 25. Zakrzewska-Bielawska, A. (2014). Dlaczego firmy chcą koopetytować? Motywy współpracy konkurencyjnej przedsiębiorstw sektora high-tech. *Zeszyty Naukowe Uniwersytetu Ekonomicznego we Wrocławiu*, Vol. 366, pp. 661-663, doi: 10.15611/pn.2014.366.62

OCCUPATIONAL HEALTH AND SAFETY MANAGEMENT IN THE POLICE: CHALLENGES AND PRACTICES IN THE CONTEXT OF MODERN OCCUPATIONAL HAZARDS

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Purpose: The purpose of this article is to analyze the occupational health and safety (OHS) management system within the Police, one of the largest uniformed services in Poland.

Design/methodology/approach: The article discusses the specific occupational hazards faced by police officers, including the risk of physical injuries, exposure to biological and chemical agents, as well as psychological burdens resulting from post-traumatic stress disorder (PTSD). It also presents the current legal regulations governing the organization and operation of the OHS service in the Police.

Findings: The paper identifies existing challenges and issues, such as the insufficient number of OHS personnel and inconsistencies in the observance of reporting hierarchies. It also emphasizes the need for further corrective and supplementary actions to improve working conditions for police officers.

Originality/value: The conclusions from this analysis may serve as a basis for implementing more effective solutions in occupational safety management within the Police.

Keywords: police, occupational health and safety service, occupational hazards.

1. Introduction

The Police is one of the largest employers in Poland, with a force of over 100,000 officers who carry out their duties in accordance with the Police Act (<https://policja.pl>, 2024). The essence of their work is to ensure safety at the individual, social, institutional, and national levels. The primary responsibilities of the Police are outlined in Article 1 of the Police Act (Ustawa, 1990), and include, among others:

- Protecting the life and health of individuals, as well as property, from unlawful attacks that violate these goods.
- Ensuring public safety and order (maintaining peace in public places, public transportation, and traffic, as well as on waterways).

- Initiating and organizing actions aimed at preventing crimes, misdemeanors, and criminogenic phenomena.
- Detecting crimes and misdemeanors and apprehending their perpetrators.
- Protecting facilities that house members of the Council of Ministers.
- Supervising specialized armed security formations.
- Monitoring compliance with administrative and public order regulations in connection with public activities or those in public places (Ustawa, 1990), and many others.

The execution of these tasks involves numerous risks (Dziedzic, 2011; Gałusza, 2018; Szankin, 2013). Work in the Police is characterized by a significantly higher-than-average occupational risk of health or life-threatening situations due to the nature of the service. Police officers operate under difficult conditions (e.g., patrolling dangerous areas, conducting interventions, and using direct coercive measures). Specific working conditions and requirements include shift work (disrupting the work-rest-sleep balance) and work-related stress. The nature of police service involves a constant state of readiness and availability to perform specific tasks (Dziedzic, 2012). This profession requires exceptional psychological and physical fitness. It is evident that police work is dangerous. Officers are at a higher risk of bodily injury, permanent disability, or even death, often as a result of actions taken against individuals they intervene with, or while participating in rescue operations during natural disasters. Depending on the duties performed, the level of risk may vary, but it is always present.

Occupational health and safety (OHS) issues within the Police are perceived differently than in typical work environments, where hazardous situations and other burdens are often a result of misperceptions of safety rules. The role of the OHS service is critical, as it provides employers with information about the state of occupational safety and health in police units. Based on this information, employers can take actions aimed at strengthening oversight in areas related to OHS. According to Article 207 § 1 of the Labor Code (Dz.U. 1974, Nr 24, poz. 141, 1974), the employer is responsible for the state of health and safety in the workplace. The obligations of employees concerning health and safety at work, as well as the delegation of OHS tasks to specialists not employed by the workplace, do not diminish the employer's responsibility. Under Article 237 of the Labor Code (Dz.U. 1974, Nr 24, poz. 141, 1974), supervisory bodies of state organizational units, including the Police, are obligated to take actions to shape safe and hygienic working conditions. This includes conducting at least one annual assessment of the state of OHS in the supervised units and indicating directions for improvement.

The assessment of the occupational health and safety management system encompasses both the identification of OHS needs (including the identification of safety hazards) and the preparation of risk analysis. Through such measures, the employer can take necessary organizational, human, and technical actions that address the defined needs of the unit in terms of improving working conditions.

The aim of this article is to analyze the occupational health and safety (OHS) management system in the Police, one of the largest uniformed services in Poland. Based on data from OHS status assessment reports in units under the supervision of the Ministry of the Interior and Administration, the article highlights the need for further corrective and supplementary actions to improve the working conditions of police officers. The conclusions drawn from the analysis may serve as a basis for implementing more effective solutions in OHS management within the Police.

2. Characteristics of occupational hazards in the Police

Occupational exposure can be defined as the exposure to dangerous, harmful, or burdensome factors associated with performing work duties (PN-N-18002). Four groups of occupational hazards can be distinguished (Ulewicz et al., 2015; Niciejewska, Kapler, 2023; Ocena stanu bezpieczeństwa i higieny pracy (służby) w 2022 r. w jednostkach podległych i nadzorowanych przez Ministra Spraw Wewnętrznych i Administracji, 2023; Rączkowski, 2024):

- **Physical hazards** (including mechanical, electrical, dust, thermal risks, noise—which can cause hearing damage, mechanical vibrations, lighting—especially during night service, optical and laser radiation, electromagnetic fields—such as those encountered when operating radar speed detectors or radios, and others. This also includes microclimate and changing weather conditions, which may cause risks related to heatstroke, frostbite, fainting, etc.).
- **Chemical hazards** (involving exposure to chemical substances and preparations, including carcinogenic substances, toxic, irritant, mutagenic substances, and lead—e.g., during fingerprinting or handling firearms).
- **Biological hazards** (caused by prions, viruses, bacteria, fungi, parasites, plant and animal factors, pathogenic microorganisms, as well as animal bites, insect stings, etc.).
- **Psychophysical hazards** (related to physical strain—static, dynamic, and repetitive tasks, psychophysical strain, and stress, including PTSD).

In terms of hazard factors, there are three types (PN-Z-08052; Ulewicz et al., 2015; Niciejewska, Kapler, 2023; Karczewski, Karczewska, 2012; Piwowarski, 2020):

- **Dangerous factors** (those that, when acting on the employee, may lead to injury or an accident at work).
- **Harmful factors** (those that can cause or lead to the onset of illnesses).
- **Burdensome factors** (those that do not pose a direct threat to life and health but hinder work and significantly impact the ability to perform tasks, reducing efficiency and causing difficulties or discomfort).

It is not without reason that police officers enjoy greater legal protection than other citizens. This is due to the greater number of dangers they may encounter during and outside of service. For example, one of the most common threats is an active assault on an officer, a hazard that is typified in Art. 222 and 223 of the Penal Code (Ustawa, 1997). This is a danger that officers must always be aware of, and although they are specially trained to handle it, in many cases, it cannot be entirely eliminated.

Another threat is direct contact with detainees (Świerczewski, 2016). This is an enforced interaction. When a police officer intervenes to arrest someone, they inevitably come into contact with the individual, which could expose them to bodily fluids such as blood, and thus to infectious diseases (e.g., HIV, tuberculosis, hepatitis, influenza, chickenpox, and others). Although there are procedures in place to reduce such risks (e.g., wearing protective gloves), it is not always possible to follow them (e.g., in dynamic interventions). It should also be noted that an officer may come into contact with blood while providing assistance. During arrests, particularly with individuals who resist and struggle, officers often find themselves in uncomfortable positions in various locations, leading to a range of injuries.

Other hazards encountered by officers during service include: contact with animals, especially dangerous dog breeds, car accidents during pursuits or even regular patrols (due to the improper behavior of drivers towards emergency vehicles such as patrol cars using lights and sirens).

Among the burdensome factors are noise, fluctuating weather conditions, air polluted with contaminated substances (sometimes exposure to toxic, explosive materials), performing procedural and non-procedural tasks in challenging conditions (e.g., inspections in basements, attics, hard-to-reach places, confined, humid areas, cold or extreme heat), as well as dealing with human aggression and interpersonal conflicts.

Police work imposes particularly high demands on those who perform it. The nature of the profession, which is tied to maintaining public safety and order, results in significant psychological and physical strain. Therefore, stress is an inherent element of this job. Post-traumatic stress disorder (PTSD) is an anxiety disorder that appears in individuals who have experienced traumatic events in their lives. Additionally, irregular working hours, weekend service (including holidays), night patrols, phone duty, and emergency shifts contribute to the health costs officers bear, affecting their mental, physical, family, social, and spiritual well-being. Given that their job involves exposure to violence, aggression, death, and shocking incidents, police officers are at risk of occupational diseases such as neurosis, depression, various addictions (particularly alcoholism), and even self-harm.

A constant element of police service is occupational risk, which arises from dangerous situations and events in which officers are involved—this risk cannot be entirely eliminated. As mentioned earlier, the Police force comprises over 100,000 officers who are exposed to numerous dangers daily. According to the Assessment of the State of Occupational Health and Safety (Service) in 2022 in Units Under the Supervision of the Ministry of the Interior and

Administration (2023), 27 types of harmful factors were monitored within the Police in 2022 (including 13 chemical, 7 biological, 5 physical, and 2 dust types), along with 5 types of burdensome factors to which both police officers and civilian employees were exposed. No upward trend in these hazards was noted.

As an example of the most significant measures taken in 2022 to minimize hazards and reduce harmful and burdensome factors, it was noted that carcinogenic or mutagenic chemical substances of hazard categories 1A and 1B were withdrawn from use within the Police force (Ocena stanu bezpieczeństwa i higieny pracy (służby) w 2022 r. w jednostkach podległych i nadzorowanych przez Ministra Spraw Wewnętrznych i Administracji, 2023).

3. Legal and organizational framework of occupational health and safety in the Police

3.1. Legal regulations governing occupational health and safety in the Police

The functioning, organization, and scope of the Occupational Health and Safety (OHS) service in the Police are regulated by the Ordinance of the Council of Ministers dated September 2, 1997, on the Occupational Health and Safety Service (Dz.U. Nr 109, poz. 704, z późn. zm., 1997). The qualifications required for individuals responsible for OHS tasks are also specifically outlined. According to its provisions, an occupational health and safety service is established within police units, which may be organized as a single-person or multi-person unit. The employer determines the number of OHS staff based on the number of employees, working conditions, and associated occupational hazards and job burdens. However, as stipulated by the aforementioned ordinance, if between 100 and 600 employees are employed, the employer must create a single or multi-person unit or employ an OHS worker in this unit on a part-time basis. If more than 600 employees are employed, the employer must employ at least one full-time OHS staff member for every 600 employees.

Regarding the reporting structure, the OHS service reports directly to the employer. In the case of an employer being an organizational unit, the OHS service reports directly to the person managing the unit or a member of the managing body or someone authorized by this body to oversee OHS matters. The definition of "employer" in the case of the Police is clarified by Order No. 916 of the Chief of Police (Zarządzenie nr 916, 2004), which states that the employer is:

- For officers serving in organizational units of the General Police Headquarters, the Chief of Police.
- For officers serving in the organizational units of the Provincial Police Headquarters (or Metropolitan Police Headquarters), the Provincial (or Metropolitan) Police Commander.

- For officers serving in county, city, and district police units, the respective County, City, or District Police Commander, and
- For officers serving at the Police Academy in Szczytno, the Police Training Center in Legionowo, and the Police Schools in Piła, Słupsk, and Katowice, the respective commanders of these institutions.

3.2. Employer and Officer Responsibilities Regarding OHS

The aforementioned Order No. 916 of the Chief of Police (Zarządzenie nr 916, 2004) adapts the provisions found in Section X of the Labor Code (Ustawa, 1974) to the Police, as well as general and industry-specific OHS regulations issued on its basis. The content of the order clearly states that the employer is obliged to provide police officers with safe and hygienic service conditions, ensuring compliance with regulations and preventing risks to the life and health of officers (Zarządzenie nr 916, 2004). Furthermore, to ensure safe and hygienic working conditions for police officers and other police employees, the following provisions are applied:

- Section X of the Act of June 26, 1974, Labor Code (unless otherwise specified by the Police Act or other special provisions).
- All general and industry-specific OHS regulations issued based on Section X of the Labor Code that can be applied to analogous work performed within the Police, as well as rules, instructions, guidelines, and standards that indicate the manner in which tasks related to the exploitation, maintenance, repair, or renovation of facilities, equipment, and gear should be carried out (§3 Zarządzenia nr 916 Komendanta Głównego Policji, 2004).

According to §4 point 2 of the Order (Zarządzenie nr 916 Komendanta Głównego Policji, 2004), the provision of safe and hygienic service conditions is to be achieved by preparing and organizing police service in a manner that prevents accidents, occupational diseases, and health conditions related to service conditions.

4. Analysis of Occupational Safety in the Police Based on Reports

Based on the "Assessment of Occupational Safety and Health (Service) Conditions in 2022 in Organizational Units Subordinate to and Supervised by the Minister of Internal Affairs and Administration," irregularities or the need for corrective actions in 2021 were observed, particularly in the area of the organizational structure of OHS. Specifically, these issues included insufficient staffing levels in the OHS services and OHS reporting lines that were not in compliance with legal regulations (Ocena stanu bezpieczeństwa i higieny pracy (służby) w 2022 r. w jednostkach podległych i nadzorowanych przez Ministra Spraw Wewnętrznych i Administracji, 2023).

An analysis of the information provided for 2022 showed that, despite efforts made, the situation regarding OHS in the Police still requires further corrective actions. For example, non-compliance concerning the number of employees in OHS services was noted in 8 units in 2021, and in 7 units in 2022. Their analysis is presented in Tables 1 and 2.

Table 1.

Organizational Status in 2021 – Units Where Non-Compliance Was Recorded

Name and location of the unit	Number of non-compliances/number of employees
KWP Lublin	1/658
CBŚP	1/700
KMP Gdynia	1/687
KMP Olsztyn	1/701
KMP Poznań	1/617
KWP Rzeszów	1/750
KRP Warszawa II Mokotów	1/710

Source: Own study based on the Assessment of the State of Occupational Health and Safety (Service) in 2022 in Organizational Units Subordinate to and Supervised by the Minister of Internal Affairs and Administration.

Table 2.

Organizational Status in 2022 – Units Where Non-Compliance Was Recorded

Name and location of the unit	Number of non-compliances/number of employees
KWP Lublin	1/678
CBŚP	1/700
KMP Gdynia	1/674
KMP Olsztyn	1/691
KMP Poznań	1/609
KWP Rzeszów	1/690 (od lipca 3 etaty)
KMP Rzeszów	1/753

Source: Own study based on the Assessment of the State of Occupational Health and Safety (Service) in 2022 in Organizational Units Subordinate to and Supervised by the Minister of Interior and Administration.

The conducted analysis of the research results (Tables 1 and 2) indicates that the situation has minimally improved. At the same time, the Chief of Police has issued directives to continue efforts aimed at increasing the number of personnel employed in the Occupational Health and Safety (OHS) units within the Police to meet the requirements set by law. Regarding the employment of OHS personnel in units where the workforce did not exceed 100 individuals, employers hired such personnel on a part-time basis or through civil law contracts (1 in the Masovian Voivodeship and 3 in the Warmian-Masurian Voivodeship) or on an unofficial basis (meaning that alongside their OHS duties, these individuals also performed other tasks but reported directly to the unit manager).

In 5 units in 2022, where the employment slightly exceeded 100 individuals, OHS tasks were performed on an unofficial basis. However, as a result of previously undertaken actions, part-time positions were established, creating a formal OHS service in 3 units: the District Police Headquarters (KPP) in Ropczyce, Kolbuszowa, and Lesko. In the KPP in Głubczyce and Wschowa, the designated OHS service carried out tasks on an ad-hoc basis, as there were no

applicants for the position. As for the issue of hierarchical subordination, in all units, their managers (except for the KPP in Strzelno) ensured the direct subordination of the OHS service to the employer, and the personnel of these services possessed the necessary education and professional qualifications (only in the KPP in Strzelno and KPP in Brzeziny (Łódź Voivodeship) were the employees in the process of acquiring the desired qualifications).

The Regulation of the Council of Ministers of September 2, 1997 (Dz.U. 1997, nr 109, poz. 704, 1997) also defines the tasks and powers of the OHS service, which include, among others, conducting inspections of working conditions and compliance with occupational health and safety regulations, continuously informing the employer about identified hazards along with recommendations for their elimination, as well as preparing and presenting analyses of the state of safety and health to the employer with proposals for initiatives aimed at preventing hazards and improving working conditions. The service is also involved in developing various documents, such as company collective labor agreements, internal regulations, instructions, and opinions on specific instructions, maintaining registers, compiling and storing OHS-related documents, participating in occupational risk assessments, providing general consulting, collaborating with laboratories, doctors (e.g., regarding periodic medical examinations of employees), and other external entities in the field of OHS, as well as a range of other activities detailed in §2 of the Regulation of the Council of Ministers of September 2, 1997 (Dz.U. 1997, nr 109, poz. 704, 1997). Among the functions of the OHS service listed in §2 point 11 of the mentioned Regulation is participation in determining the circumstances and causes of work-related accidents and in developing conclusions resulting from the investigation of the causes and circumstances of those accidents.

As for the post-accident procedures within the Police, they are governed by the Regulation of the Minister of the Interior of June 24, 2014, on the manner and procedure for determining the circumstances and causes of accidents in the Police, Border Guard, State Fire Service, and Government Protection Bureau (Dz.U. poz. 863, 2014). The diagnosed causes and circumstances of accidents required preventive decisions from the unit manager; thus, the following decisions were made: at the request of the accident investigation committees, unit managers formulated recommendations related to improving OHS conditions. As a result of these procedures, changes were made to the OHS instructions, wall-mounted handrails were installed on stairs, the rules of mutual assistance were reiterated to officers, and the use of direct coercion measures was emphasized. Special caution was advised during dynamic training exercises in the training rooms and increased attention and concentration during the performance of official duties (particularly during actions related to detaining aggressive individuals who do not comply with orders issued by officers) (*Ocena stanu bezpieczeństwa i higieny pracy (służby) w 2022 r. w jednostkach podległych i nadzorowanych przez Ministra Spraw Wewnętrznych i Administracji*, 2023).

The powers of the OHS service are detailed in §3 of the Regulation of the Council of Ministers of September 2, 1997. These include conducting inspections of occupational safety and health conditions, issuing recommendations to those in charge of employees to eliminate identified risks and occupational hazards, as well as deficiencies in occupational health and safety. It is worth mentioning the importance of inspections and audits regarding OHS, as they are effective means of evaluating the employer's compliance with the obligation to provide safe and hygienic working/service conditions for employees and highlight any irregularities and deviations from established norms through both internal and external OHS inspections.

According to the Assessment (Ocena stanu bezpieczeństwa i higieny pracy (służby) w 2022 r. w jednostkach podległych i nadzorowanych przez Ministra Spraw Wewnętrznych i Administracji, 2023), in 2021, the Police conducted 766 internal inspections and 268 external inspections, including 4 by the State Sanitary Inspection (PIS), 50 by the Technical Supervision Office (UTD), 214 inspections by the State Sanitary Inspector (PIS), and 2 sanitary inspections by the State Sanitary and Epidemiological Station (PSSE), as well as 3 audits. In 2022, 802 internal inspections and 600 external inspections were conducted (including 4 by the National Labor Inspectorate (PIP), 158 by the UTD, and 438 inspections by the PIS) and 1 audit. Following each inspection, monitoring was conducted to improve the technical and sanitary-hygienic conditions of the utilized facilities, and ergonomic equipment was replaced at workstations as resources permitted. The managers of the Police units made appropriate substantive decisions, for example, regarding solutions in the area of preventive measures concerning OHS (including the supplementation and updating of occupational risk assessment cards) and maintenance and construction works. However, priority was given to those tasks that indicated a direct threat to the health of employees and officers (for example, urgent testing of hot water for the presence of Legionella bacteria was ordered—the conducted tests showed no contamination of the water).

The identified irregularities and deficiencies, which could be eliminated without excessive financial costs, were addressed promptly, utilizing internal labor resources and the cooperation of qualified personnel specializing in repairs. Other tasks related to improving OHS conditions were included in financial plans or investment-repair plans for subsequent years. However, the implementation of high-cost proposals requiring specialized labor remains problematic. In such situations, systematic supervision is maintained concurrently by both the OHS service and the unit manager of the Police to ensure funding for achieving basic objectives in the upcoming years.

4.1. Most Common Accidents and Injuries Among Officers

In terms of the most frequent accidents and injuries occurring among officers, the Assessment (Ocena stanu bezpieczeństwa i higieny pracy (służby) w 2022 r. w jednostkach podległych i nadzorowanych przez Ministra Spraw Wewnętrznych i Administracji, 2023)

indicates that in 2022, out of a total of 4365 reported accidents involving police officers, as many as 3954 were service-related, while 411 occurred during travel to or from the place of duty. Of this total, 205 were collective accidents involving 433 officers. The most common circumstances leading to injuries sustained by officers in service included incidents during interventions arising from the statutory activities of police officers (which constituted the largest group), falls while moving, injuries during training exercises, shooting training, assaults on officers, and traffic accidents involving drivers or passengers.

There are also instances where police officers lose their lives in the line of duty. The main cause of fatalities among police officers is involvement in traffic incidents while responding to calls, during pursuits, as well as being shot or attacked with a weapon by perpetrators. It is also important to mention deaths due to COVID-19 infections during the pandemic. According to the aforementioned Assessment (*Ocena stanu bezpieczeństwa i higieny pracy (służby) w 2022 r. w jednostkach podległych i nadzorowanych przez Ministra Spraw Wewnętrznych i Administracji*, 2023), there were 5 fatalities in 2021, and 6 in 2022 (fatalities among officers were linked to activities undertaken in connection with their service).

5. Recommendations and proposals for improvement

A crucial element related to occupational health and safety is training. Programs for training, education, and professional development of police officers should encompass issues of service/work safety and hygiene (Zarządzenie nr 916 Komendanta Głównego Policji, 2004). Health and safety training is mandatory for all police officers, regardless of their position or function (Jamrozik, 2021). The scope of health and safety training includes not only principles of safety and hygiene but also various specific procedures, such as the use of firearms, driving under difficult conditions, self-defense techniques and tactics, and procedures to follow in situations involving biological, chemical, or radiological threats. Furthermore, training is focused on psychological aspects of acting under threat, stress management techniques, and coping with trauma.

Regarding the frequency and types of health and safety training within the Police, officers are required to participate in general introductory training (mandatory for anyone starting service in the police), as well as site-specific introductory training and periodic training conducted every five years (eszkoleniaBHP.com, 2024).

Additionally, the Police conducts specialized training sessions that do not fall under the categories of introductory and periodic training. In 2022, regarding employer initiatives related to promoting first aid and conducting training in this area (Kodeks Pracy, 1974), such training sessions were conducted for a total of 23,153 individuals. These training sessions covered first aid, qualified first aid, first aid in combat situations, responses to specific threats, managing

atypical behaviors, operating AED, water rescue, and principles of first aid concerning interventions with individuals whose behavior suggests potential drug use or psychological disturbances, among others (Ocena stanu bezpieczeństwa i higieny pracy (służby) w 2022 r. w jednostkach podległych i nadzorowanych przez Ministra Spraw Wewnętrznych i Administracji, 2023). An essential element of health and safety services is preventive health protection, which involves conducting medical examinations and issuing medical certificates based on those examinations.

6. Conclusion

In 2021, irregularities were identified and corrective actions were deemed necessary regarding the organization of health and safety services in the Police. These issues included an insufficient number of personnel in health and safety services and non-compliance with regulations regarding their reporting structure. Consequently, there is a need to increase staffing levels in health and safety services and ensure an appropriate hierarchical structure. Another crucial aspect is ensuring that personnel have the necessary professional qualifications. Additionally, it is essential to address the issue of so-called combined positions, where employees, besides their other duties, also perform health and safety responsibilities, which may lead to incomplete or unsatisfactory execution of tasks resulting from §2(1) (Rozporządzenie Rady Ministrów, 1997) due to excessive workload.

It is worth noting that the remuneration of health and safety service employees, compared to other positions, is not attractive, leading some personnel to resign from their roles in health and safety services for this reason. According to the Assessment (Ocena stanu bezpieczeństwa i higieny pracy (służby) w 2022 r. w jednostkach podległych i nadzorowanych przez Ministra Spraw Wewnętrznych i Administracji, 2023), the challenges and difficulties related to health and safety in the Police in 2022 included a persistent high number of vacancies, resulting in additional burdens on current officers with tasks exceeding their capacity to fulfill during their service hours, ultimately leading to physical exhaustion and professional burnout.

Therefore, it is advisable to continue efforts to:

- Supplement the number of individuals employed in health and safety services to meet legal requirements.
- Organize all organizational units to report health and safety services directly to the unit's supervisor.
- Analyze the workload of health and safety service employees in cases of non-permanent employment or the combination of health and safety tasks with other responsibilities, concerning the feasibility of task execution.

References

1. Dyduch, L. (2015). *Bezpieczeństwo realizacji policyjnych czynności lub działań*. Legionowo: Wydział Wydawnictw i Poligrafii Centrum Szkolenia Policji w Legionowie.
2. Dziedzic, A. (2011). *Klasyfikacja niebezpiecznych i szkodliwych czynników w procesie pracy wg PN-80/Z-08052*. Dąbrowa Tarnowska: Wyd. Biuro D-U BHP A. Dziedzic.
3. Dziedzic, A. (2012). *Podstawowe zasady bezpiecznej służby funkcjonariusza Policji*. Dąbrowa Tarnowska: Wyd. Biuro Doradczo-Usługowe BHP Andrzej Dziedzic.
4. Jamrozik, B. (2021). Szkolenia w dziedzinie bezpieczeństwa i higieny służby. *Kwartalnik Policyjny*, 1, p. 43.
5. Karczewski, T.J., Karczewska, W.K. (2012). *Zarządzanie bezpieczeństwem pracy*. Gdańsk: Wyd. Ośrodek Doradztwa i Doskonalenia Kadr Sp. z o.o.
6. Modern forms of occupational health and safety training as a factor influencing the development of safe and health-promoting behavior among employees (2023). *CzOTO*, vol. 5, iss. 1, pp. 370-377.
7. Ocena stanu bezpieczeństwa i higieny pracy (służby) w 2022 r. w jednostkach podległych i nadzorowanych przez Ministra Spraw Wewnętrznych i Administracji z dn. 17.10.2023 r. (Departament Kontroli DK-KKN.133.2.2023).
8. Piwowarski, J. (2020). *Nauki o bezpieczeństwie. Kultura bezpieczeństwa i redefinicja środowiska bezpieczeństwa*. Warszawa: Difin.
9. *PN-N-18002:2011 Systemy zarządzania bezpieczeństwem i higieną pracy. Ogólne wytyczne do oceny ryzyka zawodowego*.
10. *PN-Z-08052:1980: Ochrona pracy. Niebezpieczne i szkodliwe czynniki występujące w procesie pracy. Klasyfikacja*.
11. Rączkowski, B. (2024). *BHP w praktyce*. Gdańsk: ODDK sp. zo.o., sp. k.
12. Rozporządzenie Rady Ministrów z dnia 2 września 1997 r. w sprawie służby bezpieczeństwa i higieny pracy (Dz.U. 1997, Nr 109, poz. 704 ze zm.; Dz.U. 2004, Nr 246, poz. 2468; Dz.U. 2005, Nr 117, poz. 986).
13. Szankin, T. (2013). Funkcjonowanie służby BHP w Policji aspekty organizacyjno – prawne. In: Sz. Salamon, J. Tabor (eds.), *Bezpieczeństwo systemu człowiek-obiekt techniczny-otoczenie*. Częstochowa: Wyd. Politechniki Częstochowskiej.
14. Świerczewski, K. (2016). *Wybrane zagadnienia dotyczące zatrzymania osób przez Policję*. Legionowo: Wydział Wydawnictw i Poligrafii Centrum Szkolenia w Legionowie.
15. Ulewicz, R., Klimecka-Tatar, D., Mazur, M., Niciejewska, M. (2015). *Wybrane aspekty zarządzania bezpieczeństwem i higieną pracy*. Częstochowa: OWSMJP.
16. Ustawa z dnia 26 czerwca 1974 r. Kodeks pracy (Dz.U. 1998 r. Nr 21, poz. 94, z późn. zm.).

17. Ustawa z dnia 6 czerwca 1997 r. Kodeks karny (Dz.U. 1997 r., Nr 88, poz. 553).
18. Ustawa z dnia 6 kwietnia 1990 r. o Policji (Dz.U. z 2024 r., poz. 145, z późn. zm.).
19. Zarządzenia nr 916 Komendanta Głównego Policji z dnia 24 sierpnia 2004 r. W sprawie szczegółowych warunków bezpieczeństwa i higieny służby oraz organizacji służby bhp w Policji (Dz.Urz. KGP, Nr 16, poz. 98).

AI-DRIVEN INNOVATION IN BANKING – THE CASE OF COGNITIVE RPA

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Purpose: The aim of this article is to characterize the determinants and effects of implementing disruptive artificial intelligence (AI) innovations in banking operations, particularly regarding AI's relevance to the development of a new generation of robotic banking process automation systems (i.e., cognitive RPA).

Design/methodology/approach: Based on a comparative analysis of the literature and an empirical comparison of leading banks in the European Union, this article highlights the main areas of innovative improvement in banking activities through cognitive RPA applications and examines their potential to radically streamline future banking operations.

Findings: The analysis of AI innovation has found that cognitive RPA is dramatically transforming banking processes. In practice, cognitive RPA enables banks to achieve higher levels of efficiency across all dimensions of their operations, particularly in optimizing the management of a bank's wide range of risks.

Originality/value: Given the still nascent stage of AI innovation and its implementation in banking, this article combines the theoretical foundations of artificial intelligence with empirical examples from leading European banks, presenting a research area that has not yet been addressed in Polish literature and remains underexplored in global literature.

Keywords: Artificial Intelligence, Automation, Innovation Processes, Commercial Banks.

Category of the paper: Literature review, case study.

1. Introduction

Disruptive innovation in the form of artificial intelligence (AI) has been evolving since the 1950s. The AI systems focus on developing integrated decision-making algorithms that enable computer systems to perform tasks resembling human intelligence. These tasks involve complex processes of data acquisition, identification, and processing within defined boundary conditions. The application of AI facilitates real-time decision optimization through analysis of data interdependencies within vast databases (commonly known as Big Data).

When AI models are used to generate new content and make autonomous decisions, this set of activities is referred to as generative artificial intelligence. Examples of this type of AI include IT systems communicating with users in natural language (NLP), recognizing sounds, creating images, and designing decision-making processes. Generative AI has led to applications such as virtual assistants, which, in the form of avatars with speech recognition and generation capabilities, allow computers to interact with humans in an interpersonal manner.

A distinguishing feature of generative AI is the rapid development of practical applications, such as chat-based AI models (e.g., ChatGPT). In this context, banks see generative AI as a promising tool for achieving significant efficiency gains through the automation and personalization of customer service processes (i.e., front office), integrated with the optimization of back-office systems and data management in the middle office (Bielas, 2020, pp. 1-3).

The surge in the popularity of generative AI in banking is also due to its rapidly expanding range of applications. Generative AI systems have the capacity for self-improvement and automatic efficiency development. Using AI to create a specific ecosystem of data that then serves as training material for further AI models is crucial for cost reduction and resource optimization. Currently, banking systems still rely on partially automated data processing.

In this context, the purpose of this article is to characterize the factors influencing the application of AI in robotic process automation (RPA) within banking and to demonstrate the practical effects of this innovation, leading to the development of a new generation of RPA systems, i.e., cognitive RPA. The article aims to demonstrate the originality of cognitive RPA innovation as a complex integration of traditional RPA systems with machine learning and deep learning techniques within AI.

The structure of the paper is as follows. First, the literature on AI innovation is reviewed and the stages of development of Robotic Process Automation (RPA) are described. Next, the study delves into research methodology presenting results. The paper ends with the summarizing remarks.

2. AI innovation – main dimensions

Machine learning is the science of algorithms and systems that improve their decision-making and predictive performance as they learn and gain new experience. In practical terms, machine learning is an artificial intelligence technology focused on using data and algorithms to mimic human learning methods to incrementally improve decision-making and predictive accuracy (Milana, Ashta, 2021, pp. 189-209).

The idea behind machine learning is to use statistical and optimisation methods in the process of learning computers by a human (trainer), who creates algorithms to analyse datasets and identify patterns between the data, and watches over their development. Mahesh (2020, pp. 3811-382) points out that with extensive data sets and statistical methods, algorithms are trained to independently classify data, make predictions and infer from them.

In contrast, deep learning is an advanced type of machine learning using so-called artificial neural networks. Therefore, there are fundamental differences between machine learning and deep learning techniques. Deep learning shows an advantage over conventional machine learning algorithms. This advantage is due to the fact that deep learning is capable of generating more extensive and more accurate results. During deep learning applications, there is autonomous learning and self-improvement of decisions in subsequent rounds based on an extensive data set. This type of machine learning is more effective the greater the availability of training data.

Unlike other machine learning techniques, deep learning algorithms do not require the active intervention of a trainer during analysis, as the algorithms autonomously discover relationships between the data along the lines of human decision-making processes as experience increases. Deep learning requires very high computing power of computers. This is due to the processing of extensive data sets and more complex and multiple calculations (Wang, 2020, pp. 1726-1744). Also, the time required to obtain satisfactory results in deep learning models is considerably longer due to the huge amount of data and mathematical parameters and formulas. A simple machine learning algorithm can be trained adequately in as little as a few seconds to a few minutes or hours, while a deep learning algorithm may require a minimum of several hours to even several weeks to train (Kumar, Garg, 2018, pp. 22-25).

Standard machine learning algorithms typically analyse data in parts, which are then combined to produce a specific result or solution. Deep learning algorithms analyse the problem at the full scale of the data. This is because deep learning systems recognise relationships between data using the entire available database (up-bottom approach). In contrast, machine learning techniques search databases to identify human-defined types of data and their relationships (bottom-up approach) (Gutierrez-Garcia, Lopez-Neri, 2015). It does not imply that deep learning is always better than machine learning. The important thing is to choose the right solution for the specific problem. Complex deep learning algorithms using multi-layer neural networks are not necessary in every case. For some applications, it will be equally useful and more cost- and time-efficient to use simple machine learning algorithms.

3. Robotic process automation (RPA)

Traditional banking processes are often time-consuming and prone to human error. In addition, they generate a lot of forms that require manual processing and file verification, which absorbs human resources and generates high operational costs for the bank. As banks' interactions with their customers become increasingly digital, the efficient management of extensive data sets across intricate banking processes is becoming the most important cost optimization imperative for banks.

Robotic Process Automation (RPA) are based on the use of robots (so-called bots), i.e. computer programs that have been designed to independently carry out activities described by the rules of business processes. In practice, bots are a set of algorithms in which a sequence of strictly defined actions has been programmed into a given computer network. Bots perform repeatable processes, transaction patterns and tasks, with human involvement required only in exceptional cases (Nguyen, 2023, pp. 2959-2966). Bots can interact independently with other computer systems and autonomously carry out a specific data processing process from start to finish, once activated based on a schedule or condition that initiates the bot (so-called unattended RPA). There are, however, robotic process automation technologies in which bots collaborate with humans to provide support for activities performed by employees as part of more complex processes that cannot be fully automated (so-called attended RPA) (Dogc, 2022).

As a virtual workforce, RPA is a solution suitable for banks to increase the efficiency and reduce the costs of back-office banking systems as a result of the full automation of activities that are individually characterised by repetition and low added value. These activities require interaction with data from various sources, such as risk assessment systems, customer databases or external systems such as the National Bank of Poland (FINREP, COREP reporting) or reports from the Credit Information Bureau. RPA tasks are carried out within a defined sequence of data exchange between different banking systems, with large volumes and dispersion of data.

It is important to distinguish RPA from other forms of process automation, such as automatic data mining (screen scraping) or macros, which require a special development environment. RPA automates processes between applications at the user interface (GUI) level, i.e. in the environment in which humans work. As a result, developers do not need to create APIs to connect systems, so robotic banking applications are used in natural applications for employees (e.g. checking balances, preparing contracts, matching policies with contracts). The bots are programmed to understand what is on the screen, navigate across systems, identify and extract data to perform predefined actions (Axmann, Harmoko, 2020, pp. 559-562). Thus, RPA solves the problem of special process replication in the development environment, which is the case in the traditional IT systems integration model.

Banking operations generate a large number of tasks and processes, so there is plenty of rationale for implementing intelligent automation. The implementation of RPA in a bank includes all rule-based processing activities, within processes that do not require human intervention, such as logging into applications, reading and writing to databases, performing calculations, filling in forms, connecting systems via application programming interfaces (APIs), extracting data from documents or retrieving data from internal and external databases.

A particular challenge at the bank is related to unstructured data, which does not have a predefined data pattern and does not occur in a structured way. This data takes a variety of sizes and formats, i.e. textual, numerical, graphical and even audio. Traditional RPA systems face significant problems in recognising and processing unstructured data, which affects the quality of robotic output. Data processing is much simpler for structured data, which is organised in databases according to predetermined attributes and is processed after pre-labelling (i.e. semantically tagged), but such data is of a decided minority in practice.

Considering the artificial intelligence systems of robotic process automation (RPA), four phases of evolution can be distinguished:

- RPA 1.0 - assisted RPA,
- RPA 2.0 - unassisted RPA,
- RPA 3.0 - autonomous RPA,
- RPA 4.0 - cognitive RPA.

RPA with support (RPA 1.0) is being implemented in banks on individual staff workstations to automate processes. RPA bots require the intervention of employees or the system administrator. For this reason, they are most often used for customer service activities for standard tasks (e.g. handling documentation flows). Given that bots and employees collaborate on processes that are not fully automatic, assisted RPA 1.0 can be classified as a type of human-robot collaboration (ang. human-robot communication).

Unassisted RPA (RPA 2.0) is most commonly used in a bank to integrate activities in the bank's back-office systems, as it allows for full automation of processes in an end-to-end model. RPA bots operate independently and have high performance, performing tasks and interacting with other applications without the intervention of a bank employee. This type of automation is applicable to standard banking processes with exceptions, as the RPA system can only handle structured data. Consequently, the rules of operation must be based on processes running in a loop, where the data must first be transformed into structured data.

Autonomous RPA (RPA 3.0) is typically deployed in the cloud (cloud computing), enabling dynamic scaling of operations and flexible use across all the bank's business units. RPA 3.0 takes automation to a higher level of efficiency and implements more advanced processes that integrate different departments. Although RPA 3.0 introduces some aspects of artificial intelligence to process more complex tasks, it is still limited to handling structured data and has no self-optimisation capabilities. As such, workflows still rely on processes

running in a loop to structure the data that the bots can process. Autonomous RPA uses advanced predictive analytics with a system of alerts for employees in emergency situations.

The most advanced form of robotic process automation technology is cognitive RPA (RPA 4.0), which can process any type of data (both structured and unstructured data), in any format (text, image, audio, video) on a variety of media and transfer data from internal and external databases. To manage unstructured datasets, bots first transform and organise the data using advanced artificial intelligence applications such as natural language processing (NLP).

The basis of RPA 4.0 is machine learning applied to automate complex tasks to perform extensive analytical functions with high business value for the bank (e.g. updating risk models within boundary conditions set by the regulator), and in recent years also deep learning.

4. Cognitive RPA systems

Although there is no universally accepted definition of cognitive systems, the term is used to describe a set of computer technologies that, when processing data and making decisions, mimic the way the human brain works in knowledge creation. Cognitive systems make use of robotic models of processes, but rely primarily on models of artificial intelligence (Gutierrez-Garcia, Lopez-Neri, 2015). In this aspect, machine learning models for processing huge datasets from multiple sources and deep learning models for state-independent knowledge workers to generate hypotheses and formulate conclusions by recognizing hidden interdependencies in vast datasets are applied within cognitive systems (Nowak-Nova, 2018, pp. 165-167).

The goal of cognitive systems is to develop a consistent, unified, universal inference mechanism based on comprehensive data analysis inspired by the capabilities of the human mind. Cognitive systems use algorithms that can automate increasingly complex processes, simulating both human thinking and involvement in realised actions without human assistance. They have an autonomous learning capability that allows them to work through interactions with between different applications and learn from their own conclusions, extending the knowledge in the bank.

Cognitive Robotic Process Automation (CRPA) is the result of the integration of RPA and artificial intelligence (AI) methods. In addition to automation, cognitive RPA transforms banking processes into a system of efficient decision-making systems with consideration of risk and external regulation. Cognitive automation uses sets of algorithms and technological approaches from the field of artificial intelligence, such as natural language processing (NLP), fuzzy logic technologies in data mining and deep learning neural networks to create intelligent banking interfaces (Martínez-Rojas, Barba, Enríquez, 2020, pp. 161-175).

A distinctive feature of cognitive RPA is not only the automation of tasks, but the ability to learn responses in reaction to the emergence of new data or tasks. In other dimensions of RPA, such situations lead to bot stasis. Thus, cognitive robotic process automation (RPA) technology is capable of detecting and reacting to non-standard situations where risk factors or consequences of errors are very important to the bank.

Artificial intelligence systems within cognitive RPA also allow unstructured data to be processed by pre-cleaning databases of duplicate or corrupted data and defining their meaning. For this purpose, cognitive RPA bots use tools such as optical character recognition (OCR) and natural language processing (NLP). This is followed by automatic identification of data relationships, which automatically initiates decision patterns.

Artificial intelligence techniques discover the business value of data regardless of its type with very limited human involvement. As a result, so-called cognitive RPAs can autonomously assess and make for complex decisions where there are ambiguities or a range of outcome options. The processes used are then used to optimise decisions made as a result of analysing extensive large and complex data sets that come from many different sources. Thus, cognitive RPA has a distinct advantage over traditional RPA technologies, which only process structured data in well-defined rule-based tasks.

When analysing the differences between traditional RPA and RPA supported by artificial intelligence (i.e. cognitive RPA), several dimensions of the change in metrological approach can be distinguished, such as:

- methodology,
- underlying technologies,
- data processing capabilities,
- type of data,
- scope of application.

Traditional RPA uses a process-based methodology that automates activities according to conditional (i.e. 'if-then') rules. This primarily provides workflow automation through the integration of computer systems. CRPA, on the other hand, uses a methodology based on inference and knowledge building as a result of machine learning and deep learning algorithms. Artificial intelligence cognitive technologies, on the basis of identified data dependencies, give the process automation system human-like competences for inference (including predictive models). Thus, in the CRPA, the bots not only automate actions, but also learn from the data and are able to recommend courses of action and make decisions like bank employees.

Traditional RPA does not require a programming language, as it mainly involves the configuration and implementation of a defined application structure. These include the mechanism of how RPA works and how to feed a dataset of general-purpose libraries to perform specific tasks. Against this backdrop, cognitive RPA uses artificial intelligence technologies, which require pre-programmed processes and system training.

Standard RPA can only use standardised data, so it only processes data when it is available in a specific format. Meanwhile, cognitive RPA can also handle unstructured input data thanks to the advanced recognition capabilities of artificial intelligence. This exponentially increases the scope for business process automation, including task sequences that process a dataset along a specific path (work flow). The business value for the bank as a result of the combination of RPA and artificial intelligence is that the results obtained in cognitive RPA are not final on a given slice of tasks, but are part of comprehensive solutions covering the entirety of the banking systems.

5. Research methodology

The research covers the own investigation of six banks operating in the European Union to analyze the empirical applications of cognitive RPA in their activity. Based on an analysis of sample of big commercial banks selected according to their advanced technology strategy adoption. In this paper the following dimensions of cognitive CRPA activity are analysed:

- management of the bank's liquidity position (LP),
- optimisation of liquid balances in customer accounts (LB),
- application of predictive analytics for customer service (PA),
- improvement of automated supervisory reporting (SR),
- analysis of banking operations in view of risks e.g. cyber security (RI),
- optimisation of back office systems (BO),
- automation of KYC and KYB procedures (KY).

Table 1.

Cognitive RPA in research sample of the banks

Items	COGNITIVE RPA DIMENSIONS						
	LP	LB	PA	SR	RI	BO	KY
Bank 1		x	x	x			x
Bank 2		x		x	x	x	x
Bank 3	x	x	x	x		x	x
Bank 4		x	x	x	x	x	x
Bank 5	x	x	x				x
Bank 6		x		x	x	x	x

Source: Own research on the confidential banks' reports.

6. Results

The cognitive RPAs systems used to streamline the processes of identifying bank exposures to all liquidity risk (LP) are present in two out of six banks in the research sample. These systems include compliance with internal and liquidity limits and modelling and automatic alerting of intraday liquidity and collateral changes is also exploited. The CRPA system identifies intraday changes in banks' liquidity, its cost and collateral value with rapid identification of suprathreshold transactions and automatically responds to them regardless of the source of risk (i.e. internal and external). Importantly, cognitive RPA takes into account the organisational and system specificities of the two given banks.

In all of researched banks, CRPA systems streamline and automate liquidity management systems on client accounts providing better control over processes (LB). Cognitive RPA transforms manual banking processes into digital workflows, providing automated balance optimisation and error levelling. By reducing manual handling, cognitive RPA systems allow researched banks increasingly accurate prediction of liquidity balances as the range of data processed increases. This provides a rationale for the increased effectiveness of advanced liquidity analysis systems in customer service across different generic cross-sections.

The customer data is analysed in CRPA systems (PA) in almost 70% of researched banks. These banks gain insight into current needs of their customer and the risk factors associated with these relationships (so-called contextual banking). Within CRPA the banks benefit from the predictive analytics in customer data management to automatically identify customer behavior and strengthen their Customer Management systems. This allows four researched banks to react faster and offer a more personalised service with automated decisions provided in real time, thus saving time, reducing costs, minimising errors and reducing risks. The implementation of cognitive RPA is changing the way the researched banks interact with customers. Cognitive banking creates much individualized value of banking services for customers. The automated recommendation system supports the knowledge of experts and account managers, allows for the personalisation of customer service and provides instant access to analytical and transactional systems. This enables a responsive bank-customer relationship, accelerates banking service processes, provides analysis and support for operational models, which altogether creates a new dimension of proactive banking service.

More than 80% of researched banks has taken effort to streamline with CRPA regulatory reporting (SR). Thanks to the artificial intelligence tools such as natural language processing (NLP), these banks automatically extracts data from voluminous documents, reports on key legal and financial aspects and generates periodic reports for internal and external regulator use. The bots prepare automated reports so as to provide full real-time updates with compliance risks. In practice, the researched banks save time and increase the transparency of banking processes in back office systems. Cognitive RPA shortens the waiting period for bank decisions

on customer applications and leads to the elimination of manual processes during correspondence with regulators, contract preparation and customer file management.

Cognitive RPA is used in about 40% of researched banks as a solution for detecting and preventing fraud in remote channels (RI), including in particular to increase the efficiency of cyber security systems by detecting so-called vulnerabilities of the systems. In order to identify suspicious activities, algorithms check all payment transactions in real time and compare them with the transaction history within the framework of so-called early warning systems.

Thanks to cognitive technology, the process of activating services in back office systems (BO) in the half of researched bank's becomes faster and more accurate. This is especially vital in processing vast customer data where errors are identified and eliminated in real time. The back office process automation allows four researched banks to nullify the problem of erroneous forms, matching documentation (e.g. contracts with insurance policies) and reading the content of correspondence to the bank without involving bank staff. The systems will also help to generate contractual content tailored to individual customer cases and check data against legal risks, including compliance.

All researched banks use Cognitive RPA for KYC (Know Your Customer) and KYB (Know Your Business) procedures (KY) as mandatory components of money laundering and terrorist financing (AML/CT) prevention systems. Banks focus a lot of resources on verifying customers for procedures under AML policies. Due to the costly manual process, all researched banks have started to use cognitive RPAs to optimise automated processes for collecting, checking and validating customer data (e.g. identifying the beneficial owner in a large conglomerates). This ensures systemic compliance and minimizes the risks associated with money laundering, terrorist financing and other financial crimes. CRPA systems use advanced data analytics for this purpose to detect suspicious transactions in real time. AI algorithms identify inconsistencies, initiate alerts and identify areas for the bank's staff to undertake detailed KYC and KYB checks, demonstrating self-enhancing features.

7. Conclusions

The analysis of cognitive RPA applications in the researched banks indicates that artificial intelligence systems have significant potential to enhance the efficiency of process automation systems and are already finding practical applications in the banking sector. Artificial intelligence, as a disruptive innovation in the banking industry, has become an essential part of a modern bank's business structure, influencing both front-office and back-office operations.

The implementation of RPA supported by AI systems introduces a new form of assistance-cognitive RPA-which enables banks to achieve substantial strategic benefits from a holistic perspective by integrating a wide range of internal processes with diverse characteristics.

The practical cases of cognitive RPA applications presented in this paper demonstrate the capabilities of intelligent automation. They also highlight the high potential for AI development in the banking sector, particularly in the era of cloud computing and extensive database systems, where effective data management serves as the foundation for the growth and evolution of banks' operations.

References

1. Axmann, B., Harmoko, H. (2020). *Robotic process automation: An overview and comparison to other technology in industry 4.0*. 10th International Conference on Advanced Computer Information Technologies, pp. 559-562. DOI:10.1109/ACIT49673.2020.9208907
2. Biallas, M., O'Neill, F. (2020). Artificial intelligence innovation in financial services. *EM Compass*, No. 85, pp. 1-8. Retrieved from: <https://www.ifc.org/content/dam/ifc/doc/mgrt/emcompass-note-85-ai-innovation-in-financial-services.pdf>, 13.11.2024.
3. Doguc, O. (2022). Robot process automation (RPA) and its future. *IGI Global*, pp. 35-58. DOI:10.4018/978-1-7998-1125-1.ch021
4. Gutierrez-Garcia, J.O., Lopez-Neri, E. (2015). *Cognitive computing: a brief survey and open research challenges*. 3rd International Conference on applied computing and information Technology/2nd International Conference on computational science and intelligence, pp. 328-333. DOI:10.1109/ACIT-CSI.2015.64
5. Kumar, V., Garg, M.L. (2018). Deep Learning as a Frontier of Machine Learning: A Review. *International Journal of Computer Applications*, Vol. 182(1), pp. 22-25. DOI:10.5120/ijca2018917433
6. Mahesh, B. (2020). Machine learning algorithms-a review. *International Journal of Science and Research*, Vol. 9, no. 1, pp. 381-382. DOI:10.21275/ART20203995
7. Milana, C., Ashta, A. (2021). Artificial intelligence techniques in finance and financial markets: a survey of the literature. *Strategic Change*, Vol. 30(3), pp. 189-209. DOI:10.1002/jsc.2403
8. Nguyen, T.D. (2023). A survey of AI-based robotic process automation for businesses and organizations. *Science and Technology Development Journal*, Vol. 26(3), pp. 2959-2966. DOI:10.32508/stdj.v26i3.4091
9. Nowak-Nova, D. (2018). Potencjał kognitywnej robotyzacji zaawansowanych procesów biznesowych. Mit czy rzeczywistość? *Przedsiębiorczość i Zarządzanie*, tom XIX, zeszyt 5, pp. 165-167.
10. Wang, H.N. et al. (2020). Deep reinforcement learning: a survey. *Frontiers of Information Technology & Electronic Engineering*, Vol. 21(12), pp. 1726-1744. DOI:10.1631/FITEE.1900533

THE ROLE OF ARTIFICIAL INTELLIGENCE IN THE EMPLOYEE RECRUITMENT PROCESS

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Purpose: The main purpose of this article is to explore the role and importance of artificial intelligence in the employee recruitment process, with a particular focus on the impact of AI technology on the effectiveness and efficiency of recruitment management. The research objective formulated in this way aims to answer the question of whether artificial intelligence is able to provide a more effective recruitment process and minimize the risk of overlooking potential talent

Design/Methodology/Approach: The methodology of the study consists of a descriptive part on the typology of artificial intelligence and modern systems used in the process of recruiting employees in companies. The empirical part was helped by questionnaire surveys which were conducted in companies use modern recruitment methods.

Findings: Artificial intelligence is profoundly shaping economic and social dynamics, and its influence will continue to grow. The effective use of this technology has the potential for dynamic growth in various sectors, including finance. Faster sourcing of the best talent, accurate matching of candidates' skills and optimization of HR operations are just some of the benefits of automation.

Practical implications: The added value resulting from the conducted studies confirms that financial investments on capital markers of emerging countries can be an excellent alternative to the traditional financial instruments characterized by a meager rate of return.

Originality/value: The originality and innovativeness of this study has two dimensions, namely, analytical - consisting in the evaluation of modern systems of the recruitment process - indicating new opportunities for both HR professionals and employers using the innovative opportunity that is artificial intelligence.

Keywords: artificial intelligence recruitment process, management, selection, employee.

1. Introduction

With today's challenges facing businesses, competition for talent is becoming more difficult. Companies are competing not only for customers and markets, but also for outstanding employees who are key elements of organizational success. Therefore, employee selection

recruitment processes are becoming strategically important for maintaining competitiveness and achieving business goals (Michna, Grygiel 2015).

With the rapid development of technology, revolutionary changes can be seen in the field of human resource (HR) management, and recruitment processes are no exception. Modern technology and automation tools are increasingly shaping the way organizations select and hire new employees.

Selection of competent employees is one of the basic tasks of human resource management. It is a set of activities aimed at attracting the right people to the organization and bringing about the proper filling of vacant jobs to ensure the continuous and smooth functioning of the organization (Listwan, 2010). The selection process is carried out by recruitment and selection, That is, to seek and interest candidates in a job offer, check their suitability, then select the best candidate (Kardas, Multan, 2012). Increasingly, the recruitment of new employees is being done using tools that enable remote communication (Pabian, 2020) and using advanced technologies such as data analytics to ensure efficiency, service effectiveness and savings in human resource management and artificial intelligence (Migon, 2024).

Artificial intelligence is an extremely important topic, both in the context of corporate hiring and in the recruitment and selection process. Through the use of modern technology, AI has the potential to significantly increase the efficiency, objectivity and personalization of recruitment processes in various sectors. Properly implemented, AI-based solutions can dramatically change the approach to recruitment, benefiting both employers and candidates seeking employment. The added value of this article is the analysis to provide readers with valuable information and practical tips for applying artificial intelligence to their own recruitment processes.

The main objective of this article is to explore the role and importance of artificial intelligence in the employee recruitment process, with a particular focus on the impact of AI technology on the effectiveness and efficiency of recruitment management. In writing the article, it was decided to test the following research hypothesis: The introduction of artificial intelligence into the recruitment management process contributes to the effectiveness and relevance of employee selection. Addressing the issue seems to the author to be as timely as possible from both the employee and employer side. In addition, the use of AI enables a better match between candidates' skills and job requirements, resulting in higher levels of satisfaction and efficiency in the workplace.

Despite its widespread use, the definition of “artificial intelligence” remains difficult to grasp, mainly due to the ambiguity of the concept of intelligence itself. Different researchers have proposed different definitions, ranging from the general ability to adapt to new conditions and perform new tasks to the ability to perceive dependencies and relationships, learn and creatively process information.

The term “artificial intelligence” was formally introduced and defined by John McCarthy in 1955. The author of the term defined it as “the science and engineering of creating intelligent machines”. Since then, many definitions have emerged, reflecting the multifaceted nature of artificial intelligence. These definitions include the notion of machines exhibiting aspects of human thinking, including learning from mistakes, reasoning and interacting with the environment (Rózanowski 2007). The PWN Dictionary of the Polish Language defines artificial intelligence as “a branch of computer science that studies the rules governing the behavior of human minds and create computer programs or systems that simulate human thinking.

Artificial intelligence is a multidisciplinary field that includes knowledge base systems, expert systems, image recognition, natural language understanding, robotics and more. Its goal is to mimic human intelligence in machines, enabling them to autonomously adapt to changing conditions, make complex decisions and learn autonomously.

There are currently two dominant approaches to artificial intelligence: weak artificial intelligence and strong artificial intelligence. Weak artificial intelligence focuses on developing systems that simulate human cognitive functions to help solve problems and make decisions. Strong artificial intelligence aims to create machines with intelligence comparable to humans, capable of self-instruction and complex reasoning (Rózanowski, 2007).

There is no single, universally accepted definition of artificial intelligence. For the purposes of this paper, I adopt the definition proposed in the European Parliament report. Artificial intelligence is the ability of machines to exhibit human skills such as learning, reasoning, planning and creativity. Artificial intelligence works towards a specific goal, enabling technical systems to perceive their environment and possibly solve problems; it is able to analyse the consequences of previous actions and act autonomously (Parlament Europejski, 2021).

An analysis of the definitions allows us to conclude that artificial intelligence has become increasingly popular and applied more frequently in recent years. The rapid development of electronics and computer science is encouraging the development of this field of science. ‘Intelligent machines’ are needed by humans to create and discover new relationships in the world, so AI is beginning to reach into other areas of science such as medicine, economics or management. Artificial intelligence is one of the more interesting developments in computer science, absorbing a huge amount of human enthusiasm and state-of-the-art computer technology. The scope of artificial intelligence includes algorithms, heuristics, genetic algorithms, expert systems, artificial neural networks and fuzzy logic. The prospect of the emergence of intelligent machines that can think and make decisions on their own is causing anxiety among humans.

2. Literature review and methodology

The literature sources used in the article include mainly domestic as well as foreign literature, surveys and Internet sources were also helpful. These sources made it possible to analyze and show the changes taking place in the recruitment processes using modern technologies. For example, studies such as: “The employee selection process in enterprises - a review of modern and traditional selection methods”, ‘AI an ally of employers, [https://www.forbes.pl/ai an ally of employers/cjb40f1](https://www.forbes.pl/ai-an-ally-of-employers/cjb40f1)’, ‘Selection of employees for organizations against the challenges of the labor market’, or websites such as: <https://sjp.pwn.pl/sjp/sztucznaintelligence;2466532.html>, https://www.sciencedaily.com/terms/artificial_intelligence.htm, On the other hand, we can also find information on the benefits and risks of artificial intelligence for both companies, people and public services in such publications as: “European Parliament (2022)”, ‘Artificial intelligence: development, opportunities and threats’, There are also publications that refer to strategies used in companies, e.g.: “The power of artificial intelligence in recruitment: An Analytical review of current ai-based recruitment strategies”.

The statistical and scientific sources mentioned above allow an objective evaluation of the research problems under discussion and an assessment of the formulated research hypothesis. The main hypothesis states that “The introduction of artificial intelligence in the recruitment management process contributes not only to efficiency and precision in employee selection”.

3. Results

In order to verify the impact of artificial intelligence on the recruitment process of employees, a survey was conducted with 50 HR staff in various companies. The survey was conducted to show whether companies should invest in modern technologies to increase work efficiency and improve recruitment processes. The introduction of automated AI and ATS recruitment systems allows companies to contribute to the automation of processes, analysis of large sets of data, which will lead to an improvement in the quality of recruitment and reduce the time spent searching for potential candidates. In addition, it is also important to remember that the HR department should be properly trained in the use of new technologies and tools, which contributes to the efficiency of recruitment processes. The survey was divided into three thematic areas due to the very similar results of the respondents. Most focused on three aspects that were taken into account because they were crucial in answering the research hypothesis. In the first area, it was decided to investigate whether our respondents were recruited using modern technologies during their recruitment processes and whether they could consider them effective. The results of the following survey are presented in the figure below.

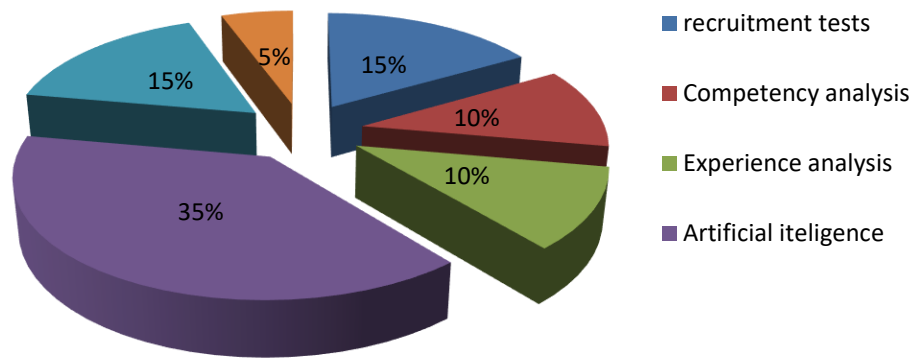


Figure 1. Respondents' opinion on whether they had to deal with a modern recruitment method during the recruitment process and which one they consider the most effective modern one.

Source: own elaboration.

Based on the survey, the most effective method among modern recruitment techniques is artificial intelligence 35%, followed by test recruiting and social media recruitment 15%. With them a little lower our respondents rated experience competence analysis 10%. In last place was outsourcing.

Modern recruitment methods as a model for supporting personnel management is an area that is developing and improving the quality and efficiency of recruitment and selection processes. This is confirmed by the opinions of respondents who are representatives of HR departments of modern companies, who note that these modern recruitment instruments are being used in their places of employment more and more often, and their effectiveness is high Figure 2.

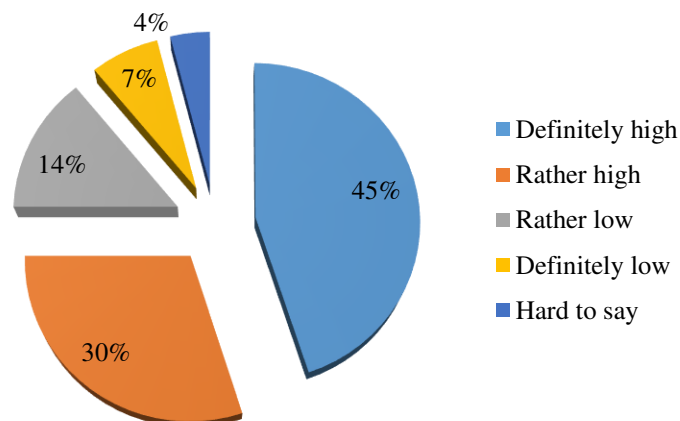


Figure 2. How respodents evaluate the effectiveness of modern methods used in the organization and what are the reasons for their use.

Source: own elaboration.

The above figure shows that knowledge of modern recruitment methods in companies is at a very high level, as evidenced by the result of 45% of our respondents. The answer of rather yes was supported by 30%, which may indicate that they have not yet had an adventure with modern recruitment methods during their recruitment. Third place at 14% was taken by the answer rather low.

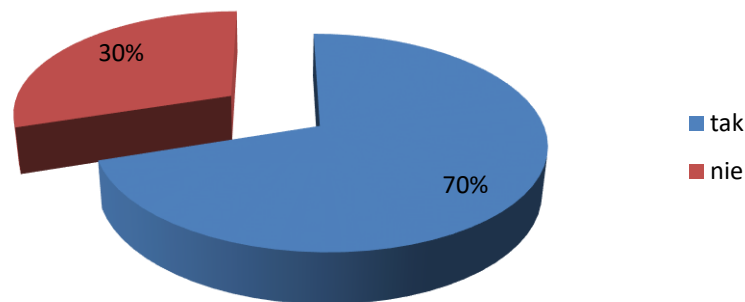


Figure 3. Do they consider the use of artificial intelligence in the retention process to be a good idea and whether they also use or would use modern tools in their companies.

Source: own elaboration.

Summarizing the results of the survey on how modern recruitment methods are used in modern companies, it was found that in most of them:

- recruitment tests, competence and experience analysis are used,
- recruitment outsourcing and recruitment through social media,
- artificial intelligence considered the most effective.

The achieved results of the survey allow us to conclude that the hypothesis was fully confirmed. Modern methods of recruitment and especially artificial intelligence are not only popular and frequently used in modern organizations, but also considered to be very effective. The modern employment market is evolving not only due to economic and technological changes and the related needs of businesses. Modern employee recruitment is increasingly relying on innovative tools that automate processes and allow for more efficient evaluation of candidates. Today, artificial intelligence is becoming an increasingly common tool in many areas of life, including its foray into the employee recruitment process. It plays a key role in automating and streamlining various stages of recruitment, from searching for candidates to assessing their competencies and aptitudes. Artificial intelligence is capable of processing huge data sets (Narvig, 2023). It meticulously and quickly searches extensive databases containing candidate profiles, both on recruitment platforms and online. AI algorithms are able to gather information on candidates' work experience, achievements and skills. AI is able to support the preparation of job descriptions and job offers. It improves the acquisition of labor market data. Artificial intelligence uses machine learning algorithms and natural language processing techniques to search for an application that meets the requirements for a given position, leaving the recruiter to evaluate the most promising candidates (Baranowska, 2021).

Taking this path further, artificial intelligence streamlines processes related to contracts or the creation and signing of documents by generating templates based on established patterns. Artificial intelligence-based systems can analyze existing documents, identify repetitive elements and recommend or create new documents based on these patterns.

Artificial intelligence technologies can be used to identify, classify and index documents based on their content. This allows systems to automatically assign appropriate categories to documents, making them easier to manage and search. Advanced systems using artificial intelligence enable electronic signing of documents (Będkowski, Brdulak, Fazlagić, 2022). Advanced systems using artificial intelligence enable electronic signing of documents. These systems can use complex cryptographic algorithms to ensure the security and authenticity of electronic signatures.

Artificial intelligence, by accessing the calendars of recruiters and candidates, can be used to schedule interviews and manage recruitment timelines. Artificial intelligence helps track contractual deadlines and track the progress of these terms. AI-based systems can generate notifications of upcoming deadlines and provide definitive contract lifecycle management. Some companies, recruitment agencies that are not equipped with recruitment systems or specialize in a variety of fields struggle with the challenge of understanding the specifics of specific positions, which are not always completely familiar to them. In such situations, Chat GPT becomes an invaluable support to generate key information about the requirements and characteristics of a particular position. Once a precisely specified question is asked within seconds, it is subjected to advanced data analysis and a wide range of information to ultimately provide the most important information needed. GPT chat can provide companies and recruitment agencies with relevant information, making it easier to match candidates with specific job needs and requirements (Alto, 2024).

AI can be used to create recruitment Chatbots. Recruiters need to keep in mind that most of the candidates they receive are not adequate and suitable to fill an empty position. Counting this, the use of Chatbots can be the first step in filtering offers. They can be implemented on websites, recruitment platforms, or even messengers such as Messenger, WhatsApp. The most interesting aspect for me is the implementation of chatbots in recruitment itself. It can be done in different ways, depending on the needs and technological possibilities (Alto, 2024).

Current Chatbots are so advanced that they are able to conduct an initial recruitment interview at any time. During such a conversation, the bot asks about work experience, skills, financial expectations and creates a profile of the job applicant based on the answers. The downside of such a form of the first stage of recruitment is that candidates often value personal approach and involvement, and at this point a significant number of candidates are able to detect that they are talking to a bot.

Another example is data analytics and big data. It has arisen as a result of the growing volume of data being generated and processed. These are data sets that are too large, complex, variable, or do not fit into the specific structures of traditional database systems to be effectively managed using traditional data analysis methods. Such huge amounts of data can be used to solve business problems that the company could not solve before.

During the implementation phase, artificial intelligence can personalize training programs to match the specific needs and learning styles of new employees. By analyzing data on employee behavior and preferences, AI systems can create personalized development plans that align with individual strengths and career goals. This tailored approach not only accelerates skill acquisition, but also increases employee engagement and satisfaction.

The role of AI extends to ongoing employee development and performance management. AI tools can monitor employee performance in real time, providing practical information to both employees and managers. This can help identify areas for improvement and development, ensuring that employees receive timely feedback and support. Additionally, AI can help create immersive learning experiences using Virtual Reality (VR) and Augmented Reality (AR), which are particularly effective for roles that require hands-on practice.

Transparency and comprehensibility of AI systems is key to building trust among employees. Employees need to understand how AI-based decisions, such as performance appraisals or promotions, are made. This requires AI systems to be interpretable, allowing users to understand and question decision-making processes. Providing employees with access to training and retraining programs is crucial to mitigating the negative effects of automation. Such initiatives can help employees transition to new roles that require human-centered skills such as creativity, empathy and complex problem solving. What's more, AI's role in performance management and employee supervision can influence workplace dynamics. While artificial intelligence can provide valuable insight into employee productivity and well-being, there is a fine line between monitoring and interference. Organizations must balance the benefits of AI surveillance with respect for employee autonomy and privacy. Clear communication about the scope and purpose of monitoring practices is essential to maintaining a positive work environment.

Artificial intelligence (AI) is a technology that complements and extends human capabilities, partially freeing humans from routine work and allowing them to focus on more meaningful and valuable tasks and solutions. In recent years, AI has become the subject of numerous debates not only among scientists and programmers who work on creating new computer algorithms, but also among other social groups, such as civil servants (seeking to use its solutions in their daily work), doctors (applying AI-based solutions in patient diagnosis) or city residents who encounter AI-based solutions on a daily basis. When discussing the widespread use and application of artificial intelligence, it is also worth mentioning its opportunities and threats, as presented in the table below.

Table 1.
Benefits and risks of using artificial intelligence

Benefits of artificial intelligence	
Type of benefit	Characteristics
For people	• improved health care; • safer means of transportation; • cheaper, customized products and services; • easier access to information, training and education; • safer workplaces (robots directed to tasks that are dangerous to humans).
For business	• development of a new generation of products and services, including in established sectors in the EU (green and closed-loop economy, healthcare, fashion, tourism, machinery manufacturing, agriculture); • increasing sales; • improving labor productivity, quality and production efficiency; • energy savings; • more efficient customer service, thereby saving time for the customer.
For public services	• cost reduction and more efficient management of education, public transportation, waste management, condition of local and regional roads, collection of property taxes, etc.; • - improving product sustainability, reducing greenhouse gas emissions, which would facilitate the achievement of the European Green Deal goals.
Strengthening democracy	• providing citizens with access to high-quality data, thereby preventing disinformation and cyber attacks; • applying data-driven controls; • minimizing the possibility of bias in recruitment decisions.
Security and safety	• crime prevention and in criminal justice (through faster processing of massive amounts of data, more accurate assessment of the risk of escaping prisoners or countering and preventing crimes and terrorist attacks); • use by online platforms to detect illegal and inappropriate online behavior; • for military purposes for defense and attack strategies in hacking, phishing, cyberwarfare.
Threats and challenges of artificial intelligence	
Underutilization of artificial intelligence systems	For the EU, insufficient use of artificial intelligence could represent poor implementation of important programs, such as the European Green Deal, loss of competitive advantage in selected economic areas, or worse living conditions for citizens.
Abuse of artificial intelligence systems	Investing in artificial intelligence solutions that will prove useless in the future.
Liability for damage caused	It is important to determine who is responsible for the damage caused by an AI-based device or service: the manufacturer, the owner or perhaps the developer? Too little liability on the part of the manufacturer will not motivate it to offer good quality AI-based goods and services, and too much liability will have the effect of limiting innovation in this area.
Threats to fundamental rights and democracy	• The results generated by artificial intelligence depend on the algorithms used and the quality of the data (risk of biased data). • Artificial intelligence can have a significant impact on privacy rights and data protection (e.g., facial recognition, online tracking and profiling of individuals). • Artificial intelligence contributes to the creation of information bubbles in social media, as well as the spread of fake videos, recordings and information through the so-called deepfake technique. • Threat to freedom of assembly and protest - using AI, it is possible to track and profile people with certain beliefs.
Impact on jobs	Risk of eliminating a large number of jobs (either through automation or major transformation) - according to the EP Think Tank's 2020 estimates. 14% of jobs in OECD countries can be highly automated.

Source: own elaboration based on: Parlament Europejski 2022.

Speaking of the benefits and risks of using AI, it is impossible not to also mention the challenges that come with its use now and in the future. Although AI is capable of solving many problems that humans would not be able to handle, we still know little about how it will affect our lives, the way we make decisions or build relationships. Even experts cannot confirm that they fully understand the operation of AI systems (the so-called black box). AI systems are currently limited to relatively narrow and well-defined tasks, and the reason for the bias of the algorithms is the human bias contained in the data. From this perspective, it is important to be aware of the shortcomings of AI systems, and in the future work on proven ways of evaluating algorithms, building transparent and reliable systems, and good human-AI relations (Craglia, 2018).

4. Discussion and conclusions

Recruitment is a way to attract new employees. For many years, all activities were carried out through traditional means i.e. sending resumes, cover letters or holding a recruitment interview at the company's headquarters. The development of technology has contributed to the creation of IT tools to support the recruitment process. Thanks to them, it was possible to analyze a large amount of information in a relatively short period of time and select people who most closely meet the expectations set by the employer. Recruitment is a way to attract new employees. For many years, all activities were carried out through traditional means i.e. sending resumes, cover letters or holding a recruitment interview at the company's headquarters. The development of technology has contributed to the creation of IT tools to support the recruitment process. Thanks to them, it was possible to analyze a large amount of information in a relatively short period of time and select people who most closely meet the expectations set by the employer.

The analysis carried out proves that the hypothesis set forth has been fully confirmed. Recent years and especially the pandemic period have caused changes in recruitment processes and accelerated many trends that have been developing in the HR field. It has resulted in more frequent use of modern methods of candidate selection, based, among other things, on the use of technology, artificial intelligence and automation of recruitment processes.

The widespread use and comprehensive impact of AI in the labor market has translated greatly into the field of human resource management. HR departments are already using AI to streamline HR processes, decision-making processes and improve the overall employee experience. Some of the key areas of AI's impact in human capital management that will almost certainly grow in importance include:

1. AI-based recruitment tools that are used to automate and optimize the recruitment process. These tools use algorithms to review resumes, conduct online assessments and match candidates. This saves HR professionals time and effort in identifying candidates, while reducing biases and improving the accuracy of hiring decisions.
2. AI can help evaluate performance by analyzing employee performance data, such as tasks completed, deadlines met, and feedback from co-workers and managers. This can help HR professionals provide more objective, data-driven feedback to employees and identify areas for improvement.
3. AI-based tools can monitor employee well-being by analyzing data on factors such as working hours, stress levels and sleep patterns. The data can help HR professionals reduce signs of burnout or other well-being issues and take proactive measures to support employees.
4. With AI, we can analyze large amounts of HR data to identify patterns, trends and insights that can help inform strategic decisions.

The considerations made allow us to conclude that in today's dynamic business environment, finding and retaining the right employees has become a key challenge for organisations. Recruitment and selection processes play a crucial role in building effective teams that can effectively support corporate goals and strategies. In this context, the development of modern recruitment and selection methods is of paramount importance for organisational success. With today's challenges facing businesses, competition for talent is becoming increasingly fierce. Companies are competing not only for customers and markets, but also for outstanding employees who are key ingredients for organisational success. In view of this, employee recruitment and selection processes are becoming strategically important for maintaining competitiveness and achieving business goals.

References

1. Alto, V. (2024). *Generatywna sztuczna inteligencja z ChatGPT i modelami OpenAI*. Warszawa: Helion.
2. Będkowski, M., Brdulak, J., Fazlagić, J. (2022). *Sztuczna inteligencja (AI) jako megatrend kształtujący edukację. Jak przygotowywać się na szanse i wyzwania społeczno-gospodarcze związane ze sztuczną inteligencją?* Warszawa: Uniwersytet Warszawski.
3. Branowska, A. (2021). Proces doboru pracowników w przedsiębiorstwach - przegląd nowoczesnych i tradycyjnych metod selekcji. *Zeszyty Naukowe Politechniki Poznańskiej*. Poznań.
4. Craglia, M., Annoni, A., Benczur, P., Bertoldi, P., Delipetrev, P., De Prato, G., Feijoo, C., Fernandez Macias, E., Gomez, E., Iglesias, M., Junklewitz, H., Lopez Cobo, M., Martens,

- B., Nascimento, S., Nativi, S., Polvora, A., Sanchez, I., Tolan, S., Tuomi, I., Vesnic Ajulevic, L. (ed.) (2018). *Artificial Intelligence. A European Perspective*. Luxembourg: Publications Office.
5. https://sjp.pwn.pl/sjp/sztuczna_inteligencja;2466532.html, 14.09.2024.
 6. https://www.sciencedaily.com/terms/artificial_intelligence.htm, 14.09.2024.
 7. Kardas, J.S., Multan, E. (2012). *Dobór pracowników do organizacji wobec wyzwań rynku pracy*. Siedlce: Wydawnictwo Uniwersytetu Przyrodniczo-Humanistycznego.
 8. Kowalik, A. *AI sprzymierzeńcem pracodawców*, <https://www.forbes.pl/aisprzymierzencempracodawcow/cjb40f1>, 17.10.2024.
 9. Listwan, T. (2010). *Zarządzanie kadrami*. Warszawa: C.H.Beck.
 10. Michna, A., Grygiel, K., Grygiel, P. (2015). Rekrutacja oraz system motywacyjny pracowników jako element zarządzania zasobami ludzkimi w wybranej jednostce administracji publicznej, *Zeszyty Naukowe Politechniki Śląskiej, Organizacja i Zarządzanie*, z. 78, Nr kol. 1928.
 11. Migoń, B. *Rewolucja w zarządzaniu zasobami ludzkimi: Jak automatyzacja zmienia procesy HR*, www.eqsystem.pl, 5.10.2024.
 12. Pabian, A. (2021). *Rekrutacja i selekcja pracowników w dobie pandemii w województwie śląskim*. Pobrano z: <https://us.edu.pl/rekrutacja-i-selekcja-pracownikow-w-dobie-pandemii-w-wojewodztwie-slaskim-badania-dr-angeliki-m-pabian/>, 12.09.2021.
 13. Parlament Europejski (2022). *Sztuczna inteligencja: szanse i zagrożenia*, <https://www.euro-parl.europa.eu/pdfs/news/expert/2020/9/story/20200918STO87404/20200918>
 14. Różanowski, K. (2007). Sztuczna inteligencja: rozwój, szanse i zagrożenia. *Zeszyty Naukowe Warszawskiej Wyższej Szkoły Informatyki*, no. 2. STO87404_pl.pdf, 1.01.2023.

TIG WELDING OF TITANIUM ALLOY TI-6AL-4V FOR AUTOMOTIVE APPLICATIONS

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Purpose: The main novelty of the paper is to present the Ti alloy welding for automotive application. Welding titanium is a difficult task. The aim of the article is to develop the MIG (Metal Inert Gas) welding process for titanium alloys and to indicate the correct process parameters.

Design/methodology/approach: Various parameters of the titanium alloy welding process were tested and then the quality of the obtained joint was checked by the mechanical tests.

Findings: The correct process parameters were determined and the properties of the joint were compared with the properties of the base material.

Research limitations/implications: In the future, it can be suggested to investigate the effect of modified shielding gas mixtures (Ar-He) for the MIG welding.

Practical implications: The proposed process innovation will result in savings of production cost, because titanium and its alloys are suggested to be welded in a vacuum, which is a much more expensive process.

Social implications: By modifying the process, environmental protection is not impaired, EU directives on reducing CO₂ emissions (carbon footprint) are fulfilled.

Originality/value: It is to propose a new solution in automotive industry. The article is especially addressed to manufacturers of titanium alloys for means of transport.

Keywords: automotive, titanium, welding, transport, production savings.

Category of the paper: Research paper.

1. Introduction

The costs of titanium welding can be significantly reduced by several different methods, with an emphasis on process optimization, minimizing material losses and selecting appropriate welding technologies. The most important aspects that can help you reduce costs are following (Yee et al., 2023):

1. Optimization of welding processes - Selecting appropriate welding parameters, such as current, voltage and welding speed, allows you to minimize energy consumption and reduce the amount of impurities.
2. Use of pulse welding - Compared to traditional welding, pulse welding can reduce energy consumption and reduce the amount of heat introduced into the material, which is important when working with titanium, which is susceptible to oxidation.
3. Protection against oxidation - Titanium easily reacts with oxygen, which affects its properties and increases welding costs (due to the need for rework). The use of an atmosphere of inert gases (e.g. argon) allows to limit this reaction, which results in higher quality of welds and lower costs.
4. Process automation – Automation of titanium welding, e.g. using welding robots, allows for repeatability and precision, which reduces the number of defective welds and the need for corrections.
5. Minimizing material thickness – In applications where it is possible to reduce the thickness of titanium, material consumption and welding costs can be reduced. However, careful analyzes must be carried out to maintain the appropriate strength of the structure.
6. Modern welding technologies – Techniques such as laser or electron welding make it possible to achieve high-quality welds with lower energy costs and smaller material deformations.

The paper presents the results of various TIG (Tungsten Inert Gas) welding tests for titanium alloy Ti-6Al-4V. Titanium welding is a process used when working with metals that are difficult to weld because it allows for high-quality and precise connections. Titanium is characterized by high strength and corrosion resistance, making it an ideal material for applications in aviation and automotive. However, TIG welding of titanium requires special conditions to avoid problems such as oxidation and weld brittleness. Titanium and its alloys have better anti-corrosion properties than steel, but they are much more difficult to weld (Jaewson et al., 2011; Darabi et al., 2016). Titanium reacts very easily with oxygen, nitrogen and hydrogen, especially at high temperatures, which can lead to brittleness and loss of mechanical properties of the joint. Therefore, during welding, effective protection with shielding gas (usually argon or helium) is necessary (Golański et al., 2018, pp. 53-63; Skowrońska et al., 2017, pp. 104-111). The use of high purity argon (at least 99.995%) is necessary to avoid gaseous impurities. Helium is sometimes used as an additive gas because it improves arc penetration and stability, but the medium is less popular due to its higher cost. When welding steel, there are no such stringent requirements (Fydrych, Łabanowski et al., 2013; Shwachko et al., 2000).

The deciding TIG welding parameters are:

- type of wires,
- composition of gas mixtures (Ar-He) in TIG welding,
- pre-heating temperature.

The surface of welded titanium must be perfectly clean - any contamination, fat or oxide residues may deteriorate the quality of the weld. It is recommended to clean the surface with isopropyl alcohol or special preparations. The tungsten electrode must be properly sharpened and clean (Rehman et al., 2021).

Welding titanium requires relatively low current because the material has low thermal conductivity, which means it heats up quickly. Overload may lead to melting or deformation of the material. Welding too slowly may result in excessive heating, which promotes oxidation, while welding too quickly may result in incomplete penetration (Faraji et al., 2021).

Properly selected welding speed allows you to obtain a smooth weld. In addition to the main shielding gas, additional protective shields (e.g. shielding chambers or back surface protection tools) are often used to prevent oxidation of the weld at the interface (Li et al., 2023). Titanium has two allotropic varieties (alpha hcp and beta bcc). Ti-6Al-4V alloy is the most widely used and most popular titanium alloy, containing aluminum (6%) and vanadium (4%). It is strong, resistant to corrosion and can be easily welded and heat treated. Thanks to its universal properties, it is used in various industries. This alloy has a two-phase ($\alpha + \beta$) structure (Piao et al., 2023).

7. Materials

For titanium alloy Ti-6Al-4V welding the austenitic electrode wire 309LSi was selected. For titanium alloy welding the TIG (Tungsten Inert Gas) method, specialized rods are used, which are selected depending on the type of alloy and the mechanical requirements of the finished weld. Here are some of the most commonly used titanium alloy welding rods:

- Grade 5 titanium rods (Ti-6Al-4V) – is the most popular titanium alloy used in industry, due to its excellent mechanical properties and fatigue strength.
- Grade 23 titanium rods (Ti-6Al-4V ELI) – is a variant of the Grade 5 alloy with a reduced level of impurities, especially oxygen.

The main direction of research was the modification of shielding gas mixtures in the TIG process containing Ar and He and two types of rods (Grade 5 and Grade 23). Preheating before TIG welding of titanium alloys is usually kept to a minimum or often omitted because titanium has a low thermal conductivity, which causes the heat to concentrate in the welding area. A thickness of weld was 2 mm. Table 1 presents the mechanical properties of Ti-6Al-4V alloy.

Table 1.
Tensile strength of tested material

Ti alloy	YS, MPa	UTS, MPa
Ti-6Al-4V	820	960

The mechanical properties of the alloy results from their various chemical composition (Table 2). These good mechanical properties of the alloy are the result of the chemical composition, which affects the structure of the alloy (alpha + beta). The alpha phase is responsible for good plastic properties, and the beta phase guarantees high tensile strength.

Table 2.
Chemical composition of tested grades of steel

Ti alloy	C	Al	V	Fe	O	N	Cr	Mo	Ti
Ti-6Al-4V	0.07	5.9	4.1	0.2	0.01	0.04	0.4	0.6	bal

The analysis of the table shows that the alloy contains alpha phase stabilizers: Al, and O, N, C (which are treated rather as impurities in titanium alloys) and beta phase stabilizers, which are primarily vanadium and Fe, Mo, Cr. The main alloying elements are Al and V, which is consistent with the symbol of the alloy.

It was decided to realize welding process of 2 mm thickness without chamfering. The rod diameter in all cases was 2 mm. The weld was formed as single-pass. On the root side, the joint was protected by a ceramic forming backing.

At the beginning of welding process, the current and the voltage parameters were suggested:

- welding current: 106 A,
- arc voltage: 22 V.

Other important welding parameters were determined as follow:

- welding speed: 60 mm/min,
- shielding gas flow: 17 dm³/min.

The joints were made with a several combinations. The most important element of investigation included checking the preheating temperature and selecting of proper shielding gas mixture for TIG welding process containing:

- Ar-18% - 5% He.
- Ar-18% - 10% He.
- Ar-18% - 15% He.

The use of high purity argon and helium (at least 99.995%) is necessary to avoid gaseous impurities. Helium is sometimes used as an additive gas because it improves penetration and arc stability, but there is no clear opinion on the most favorable He content in Ar-He mixtures. Purpose of adding helium to the gas mixture when welding titanium:

1. Increasing the energy of the welding arc - helium has a higher thermal conductivity than argon, which results in a higher arc temperature.
 2. This results in better material penetration and a more stable welding process.
- Also a very important element of the research was to eliminate preheating temperature.

8. Methods

After the welding process with various parameters, non-destructive test (NDT) and also some destructive tests (DT) were carried out to assess the best quality of the joints.

Initially some NDT were carried out:

- VT - visual test corresponded with → PN-EN ISO-17638 standard.

Then, some DT testing were carried out:

- tensile strength → PN-EN ISO 527-1 standard,
- bending test → PN-EN ISO 7438 standard.

9. Results and discussion

The dissimilar joints were made using two rods (Grade 5 and Grade 23) and three different of shielding gas mixtures without pre-heating temperature. In total, 6 different welds were made, marked with samples from E1 to E6 (tab. 4).

Table 4.
Samples designations

Sample	Shielding gas mixture	rod
E1	Ar-18% - 5% He	Grade 5
E2	Ar-18% - 5% He	Grade 23
E3	Ar-18% - 10% He	Grade 5
E4	Ar-18% - 10% He	Grade 23
E5	Ar-18% - 15% He	Grade 5
E6	Ar-18% - 15% He	Grade 23

NDT tests were performed for all samples (E1-E6) after welding process. Most of the samples (E2, E3, E4, E6) were defect-free (column rows marked in green colour), but two samples (E1, E5) were made incorrectly (column rows marked in pink colour). The NDT results with comments on the observations during inspection are presented in Table 5.

Table 5.*NDT results for tested dissimilar welds*

Sample	Observation
E1	Small cracking in HAZ
E2	Correct weld, defect free, correct form and dimension of HAZ
E3	Correct weld, defect free, correct form and dimension of HAZ
E4	Correct weld, defect free, correct form and dimension of HAZ
E5	Small cracking in weld from the face and root sides
E6	Correct weld, defect free, correct form and dimension of HAZ

It was found that the choice of Grade 23 rod gives better results than Grade 5 rod. In turn, the helium content of 10% in the argon shielding mixture guarantees a correct joint. Helium (in range 10%) improves the flow of shielding gas, which can help keep the weld zone clean, reducing the risk of contaminants (such as nitrogen, oxygen or hydrogen) that can lead to weld defects such as pores. Helium helps stabilize the welding arc (samples E3, E4), which is important in the TIG process, where precise control of the arc is key to obtaining a high-quality weld. However, too high a helium content in the shielding argon mixture may stop the electric arc stabilization process and may lead to deterioration of the joint properties (sample E5). Titanium can easily form oxide and nitride inclusions, so it is important that the welding zone is properly protected. The next element of the research was to perform a tensile strength test. Only samples that tested positive in NDT tests were taken into account for destructive testing (E2, E3, E4, E6). The tensile strength tests were performed at room temperature (19°C). Table 7 shows the tensile strength (UTS) of the joints.

Table 7.*Tensile strength of joints*

Sample	UTS [MPa]
E2	679
E3	718
E4	705
E6	687

The data from the tab. 7 indicate that it is possible to achieve high tensile strength of the tested joints over the 650 MPa. It was noticed that the joint made of Grade 5 rod had the best strength, which indicates that small impurities in the rod can strengthen the weld. This is a very interesting observation also from the point of view of savings in production, because Grade 5 rod is 20% cheaper than Grade 23.

As the last part of the article a bending tests was carried out. Measurements were done from the face and from the root sides of the joint. A bending test was performed at ambient temperature. The observation and results of bending test are presented in Table 8.

Table 8.*Bending test of dissimilar weld*

Sample	Face side	Root side
E2	No cracks	No cracks
E3	No cracks	No cracks
E4	No cracks	No cracks
E6	No cracks	No cracks

The bending tests were very positive, no cracks were observed in all samples. This proves very good properties of the thin-walled titanium alloy joint.

10. Summary

The article presents the principles of welding the Ti-4Al-6 alloy used in the automotive industry in terms of cost savings. Various parameters of the TIG welding process were analyzed. The quality of joints welded using non-destructive and destructive methods was assessed. The influence of various rods and shielding gas mixtures was tested. TIG welding can effectively replace the much more expensive welding process in a vacuum chamber. Joints with very good mechanical properties were obtained.

Based on the research study, the following conclusions were given:

1. Welding of alloy Ti-4Al-4V using TIG method allows for process savings.
2. All welding parameters should be selected very precisely.
3. The most important parameters of the titanium alloy are chemical composition of rod and shielding gas mixture.
4. The best welding results were obtained when simultaneously:
 - the preheating temperature was not used,
 - the shielding gas mixture should contain Ar-18% - 10% He,
 - an electrode wire should have austenite structure.

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References

1. Darabi, J., Ekula, K. (2016). Development of a chip-integrated micro cooling device. *Microelectronics Journal*, Vol 34, Iss. 11, pp. 1067-1074, <https://doi.org/10.1016/j.mejo.2003.09.010>.
2. Faraji, A.H., Maletta, C., Barbieri, G., Cognini, F., Bruno, L. (2021). Numerical modeling of fluid flow, heat, and mass transfer for similar and dissimilar laser welding of Ti-6Al-4V and Inconel 718. *International Journal of Advanced Manufacturing Technology*, 114(3-4). <https://doi.org/10.1007/s00170-021-06868-z>
3. Fydrych, D., Łabanowski, J., Rogalski, G. (2013). Weldability of high strength steels in wet welding conditions. *Polish Maritime Research*, Vol. 20, no. 2/78, 67-73. <https://doi.org/10.2478/pomr-2013-0018>
4. Golański, D., Chmielewski, T., Skowrońska B., Rochalski D. (2018). Advanced Applications of Microplasma Welding. *Biuletyn Instytutu Spawalnictwa w Gliwicach*, Vol. 62, Iss. 5, 53-63. <http://dx.doi.org/10.17729/ebis.2018.5/5>.
5. Jaewson, L., Kamran, A., Jwo, P. (2011). Modeling of failure mode of laser welds in lap-shear specimens of HSLA steel sheets. *Engineering Fracture Mechanics*, Vol. 1, pp. 347-396.
6. Lee, Y.J., Jeong, W.K., Lee, S.J., Fujii, H., Shin, S.E., Lee, D.G. (2023). Effect of welding conditions on microstructural evolution of friction-stir-welded ti-cu plate. *Archives of Metallurgy and Materials*, 68(1). <https://doi.org/10.24425/amm.2023.141486>
7. Li, Y., Liu, Q., Li, J., Liu, C., Wu, Z. (2023). Molecular Dynamics Simulation of Diffusion Behavior of Ti/Al Explosive Welding Interface. *Xiyou Jinshu Cailiao Yu Gongcheng/Rare Metal Materials and Engineering*, 52(6).
8. Piao, Z., Zhu, L., Wang, X., Liu, Z., Jin, H., Zhang, X., Wang, Q., Kong, C. (2019). Exploitation of Mold Flux for the Ti-bearing Welding Wire Steel ER80-G. *High Temperature Materials and Processes*, 38. <https://doi.org/10.1515/htmp-2019-0040>
9. Rehman, A.U., Babu, N.K., Talari, M.K., Usmani, Y.S., Al-Khalefah, H. (2021). Microstructure and mechanical properties of dissimilar friction welding ti-6al-4v alloy to nitinol. *Metals*, 11(1). <https://doi.org/10.3390/met11010109>
10. Shwachko, V.L. (2000). Cold cracking of structural steel weldments as reversible hydrogen embrittlement effect. *International Journal of Hydrogen Energy*, no. 25.
11. Skowrońska, B., Szulc, J., Chmielewski, T., Golański, D. (2017). Wybrane właściwości złączy spawanych stali S700 MC wykonanych metodą hybrydową plazma + MAG. *Welding Technology Review*, Vol. 89(10), 104-111. <http://dx.doi.org/10.26628/ps.v89i10.825>.

WORKSHOP ACTIVITIES AS AN ESSENTIAL PART OF ARCHITECTURAL EDUCATION. MOSAIC

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Purpose: The purpose of the article is to present the results of the work on the design and realization of the mosaic carried out within the subject of Sculpture at the Faculty of Architecture, Interior Design Faculty.

Design/methodology/approach: The article discusses the work of first- and second-year students of the Faculty of Architecture on the design and realization of a mosaic set in a specific cultural context relating to the identity features of the place for which it was dedicated. The methods of work, the design and execution process and the results of the work are presented. The workshop activities undertaken help to visualize to students the importance of art in architecture, as well as allow them to acquire soft skills needed in the modern world.

Findings: The study showed that participation in the mosaic-making workshop significantly supports the development of students' creativity, interpersonal skills and social awareness. By working in a team and completing 1:1 projects, workshop participants gained valuable experience in communication, decision-making and time management, which is crucial for their future careers. Moreover, the practical experience of working on mosaics allowed students to better understand the artistic value of this medium in public spaces, as evidenced by the survey results, in which 98.3% of respondents expressed their belief in the need for the presence of mosaics in contemporary architecture.

Originality/value: Universities and colleges, including architecture faculties, are constantly looking for innovative teaching methods to improve the quality of education. The article addresses the issues of artistic creation in a spatial context, fine arts in architecture as a factor in developing the artistic and research area in the Interior Architecture major at the Faculty of Architecture of the Silesian University of Technology in Gliwice, Poland.

Keywords: architectural engineering education, course assessment, studio teaching method, institutional culture, student-centered learning.

Category of the paper: Case study.

1. Introduction

Workshop activities have an important role in the teaching process, especially in the context of architectural education. In order to improve the quality of education, universities, including faculties of architecture, are constantly looking for innovative teaching methods. This article focuses on artistic creation in a spatial context and visual arts in architecture, examining their impact on the development of the artistic and research field. An analysis of the students' work on the design and realisation of a mosaic as part of the Sculpture course at the Faculty of Architecture at the Silesian University of Technology was carried out, paying attention to the working methods, design process, results and survey results. The conducted research confirms the significant impact of workshop activities on the development of students' creativity and artistic awareness, their communication skills and cooperation at each stage of the process. The article presents workshop activities as an important element of architectural education, stimulating sensitivity to art and enabling the acquisition of various competences necessary in the contemporary world.

2. State of research

There is now a significant interest in workshop activities as an important element of architectural education, which is reflected in academic studies. Research focuses on the use of various artistic activities, such as drawing, painting or sculpture, in the process of improving design skills. The papers highlight the important role of artistic subjects in the formation of architects' competencies. Makowska (2019) pointed to innovative teaching methods that improve the creativity of landscape architecture students. Similarly, Żychowska (2019) highlights the importance of teaching drawing to the new generation of architectural engineers. Zabawa-Krzypkowska and Groń (2019) analyse architectural and artistic activities in the context of public space, highlighting the creative teaching of architecture students through murals. Wesółowski (2022) presents methods to enhance architectural engineering students' acquisition of technical and soft skills.

Artistic and research projects and activities that go beyond the standard curriculum are also analysed, aiming to make students aware of the importance of art in architecture and the development of so-called soft competencies, which contribute to increased competitiveness in the labour market. The works of Wesółowski, Muszyńska, Ceylan, Soygenis and other authors point to the relevance of these activities in the context of contemporary professional challenges.

The aim of this paper is to provide a holistic account of the didactic process, which was not only to complete a specific task - designing and making a mosaic - but also to explore what benefits both the tutors and students noted from the workshop work.

3. Methods

The long-term teaching experience of the authors of this article makes it possible to determine how the process of teaching visual arts develops visual skills, stimulates the imagination, sensitises, and helps to gain knowledge about visual arts in architecture. The skills acquired in the course allow students to realise their own concepts at different scales in architecture. They make it possible to work with a variety of tools to present their own design and artistic concepts to future investors.

Participatory observation during the entire creative process from the creation of the design work through to the execution process allows summaries to be made regarding the undertaking undertaken. The review of the works taking into account all the problems, as well as the student surveys, allow conclusions to be drawn which are helpful for the implementation of the curriculum, aimed at enriching the programme (including workshop activities).

Part I reviewed the student work. Based on observations during the creative process, the benefits and problems encountered at each stage of the assignment were analysed. In Part II, a student survey was conducted.

4. Background

Artistic subjects: Drawing, Painting, Sculpture, Basics of Design play a special role in the didactic process at the Faculty of Architecture of the Silesian University of Technology in Gliwice. The current curriculum of visual arts education at the Faculty of Interior Design was developed by architects and visual artists. The shape of education has evolved, subject to modifications (recently mainly due to curriculum changes and problems related to the Covid 19 pandemic). In the academic year 2021/2022, in the summer semester, as part of the Sculpture course, groups of six students realised a new theme - a large-scale mosaic project. The theme of the mosaic was determined by the subject instructors and related to the city of Gliwice and the Silesian University of Technology. The project was therefore to be set in a specific cultural context. An important aspect of the classes was to draw the students' attention to the role of the architect in the design process, as a person who inspires the potential investor in terms of understanding the location or selection of a site for an investment, and understanding its character. The analysis of the location included the architectural and landscape context and cultural value. Attention was paid to existing elements in the space such as scale, rhythm, subdivision and the colour of the surroundings.

5. Didactic process

As part of the introduction to the design subject, the students received as comprehensive a theoretical introduction as possible to the ceramics and realisations in the various historical periods of mosaics in and around Gliwice.

An initial acquaintance with the theory - literature, photo-documentation, catalogues - was followed by discussion and an exchange of experiences with the subject instructors. The students were given an initial overview of the technique, which was undergoing a renaissance, and were briefly introduced to both technological and pre-technical possibilities. At the same time, the outline of future activities and their planning began to emerge, an extremely important design phase that gave the student an idea of the goal towards which he or she could consciously work. Important at this stage of work was the search for motifs and contexts, including extremely important references to the places where the realisations would be presented - temporarily and permanently.

Notes, photographs, handwritten sketches or those using graphic tablets began to appear in large numbers. The whole process was accompanied by lively discussions, insights arising from various reflections, and the first conclusions were drawn.



Figure 1. Example of a presentation board prepared as part of the course Furniture design.

Source: Natalia Gach.

6. Design process

The first stage of the work was conceptual work - looking for inspiration, then visualising the idea in the form of a drawing and selecting the most interesting proposal. The students then made templates on a scale of 1:1, i.e. 150 x 150 cm. This part of the work took place at the Architecture Department of the Silesian University of Technology in Gliwice.

The review of the prepared proposals was followed by the selection of designs for implementation. The work took place in several interrelated stages and in a strictly defined order:

1. determining the scale and context of the site,
2. design selection,
3. colour development,
4. development of stencils - on tracing paper, foil, cardboard.

12 mosaics were created, 50% of the works related to Gliwice, 50% of the studies were connected with the Silesian University of Technology. All projects were accepted for further elaboration.

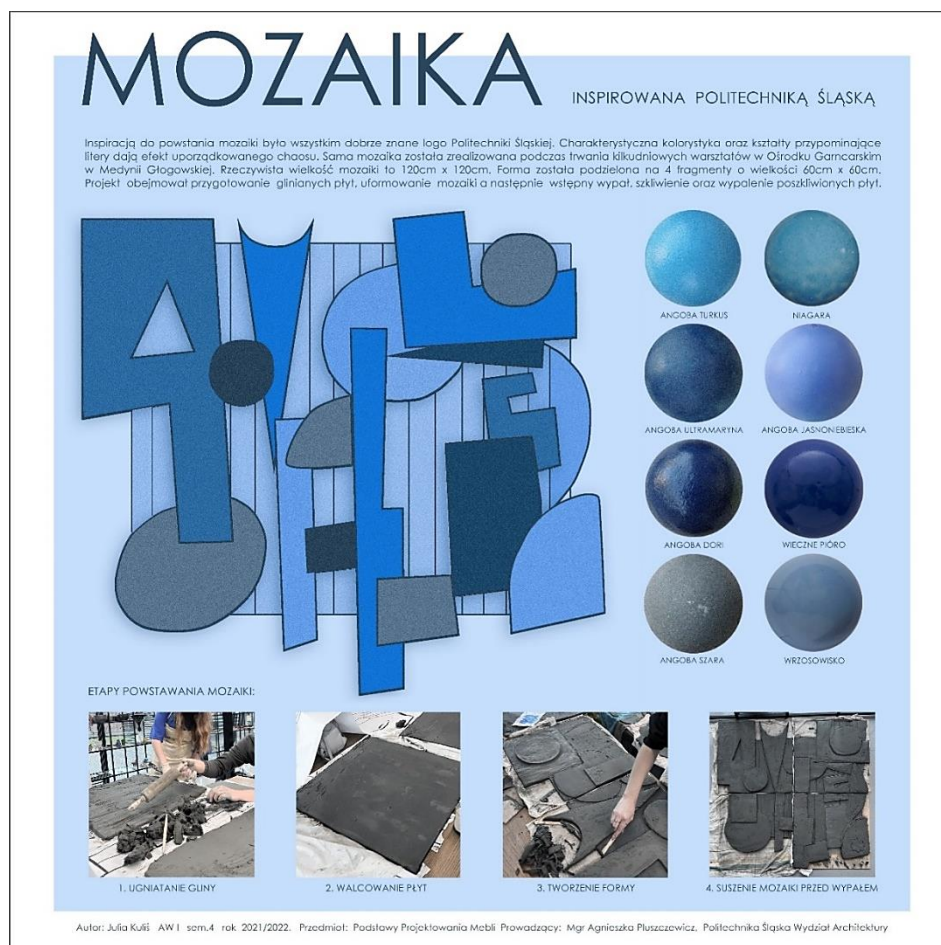


Figure 2. Example of a presentation board prepared as part of the course Furniture design.

Source: Julia Kuliś.

The next stage of the work involved a trip to the Pottery Art Centre in Medynia near Łańcut and making the designed mosaics on site. Pottery and ceramic workshops were held on 4-5.04 and 25-26.04.2022. A total of 74 students divided into two groups of 42 and 32 participated in the workshops.

The first stage was to roll the clay, establish the divisions, apply the design with templates to the target format of 120 x 120 cm, which resulted from the size of the clay kiln chamber, and then cut into mosaic pieces. This was followed by the next stages of the work: firing and glazing.

7. Technology

During the workshop work, it was decided to use high-fusing clay with the addition of chamotte, as it is more resistant to increased temperature amplitudes and humidity fluctuations.

In order to get a feel for the possibilities of the different types of ceramic clay before proceeding with the actual mosaics, tests were made on small formats referring to the size of a traditional tile. A number of interesting and stylistically diverse, although describing a similar theme, small sculptural sketches were produced. In each work, the thematic reference was the city of Gliwice with its characteristic motifs and the Silesian University of Technology, including the university's logo. Methods of moulding clay and tools of various types were tested.



Figure 3. Preparation of a 1:1 scale template and application of the template, ordering of elements.

Source: Joanna Zabawa-Krzypkowska.

During the workshop, rolling and hand modelling using various tools were chosen as the method of moulding the clay. In addition, the students had the opportunity to try their hand at turning clay on the potter's wheel and produce rotating forms. Bowls, plates, cups and vases were created.

Firing (also known as baking) is a high-thermal chemical reaction that involves the physical conversion of soft, plastic clay into hard clay, during which various component-dependent gases are also released. This is a process of raising the temperature over a period of several hours to several days, followed by a second ascent.

It was decided to have firing under maximum control, i.e. in an electric kiln with a controller (microcomputer) and the possibility of setting the firing curve individually, thus minimising the risk of damage to the firing piece.

The final stage of the work was glazing, which took place in 2 stages - a theoretical stage and then a practical stage. The theoretical stage was extremely important, as it gave the authors of the work an initial idea of the effects, as well as the risks that occur during glazing. One method of glazing is the brush application method, which allows colours to be combined within a single plane. Colour is obtained by adding oxides, respectively: to obtain white - tin is added to ground glass dust, yellow - iron compounds, violet - manganese compounds, blue - cobalt, and green - copper. The students' work was glazed using the brush painting method.



Figure 4. Glazing process and presentation of finished mosaics.

Source: Joanna Zabawa-Krzypkowska.

8. Questionnaire surveys

The work carried out on the mosaic was followed up by surveys, which completed the teaching and research process. The survey was conducted after the completion of the exercises and workshops among the students.

The survey was divided into two parts that addressed two issues:

- The general issue was to identify whether students knew the answer to the question: what is a mosaic and whether they could identify examples of mosaics in urban spaces. Then, on the specific examples of mosaics selected for the study, students expressed their individual opinion about them.
- The specific issues involved working on the creation of a mosaic in class and then creating one in a workshop in Medynia Głogowska.

For the vast majority of students, working with clay was a new experience, with as many as 45% responding that they had never had the opportunity to do so, and 35% of those surveyed had only carried out a sculptural task in the past (the moulding process alone, without firing or glazing), and only 12 people (20%) had previous experience with glazing and firing ceramic works. This shows that the majority of students were encountering a traditional craft technique for the first time, and that the large-scale project stage and the contact with the material were among the two most frequently indicated as the most difficult experience (32.8% of responses). The conceptual stage associated with generating ideas (39.3% of respondents), seeking inspiration (13.1%), and planning mosaic divisions and colour schemes (8.2%) were also challenging.

Further information about the difficulties encountered during the work was provided by additional open questions. Students indicated as problems in the design phase, among others: dividing the design into small matching elements without losing out on form, fitting in with the design brief, finding inspiration and ideas for a comprehensible, original and interesting mosaic form, lack of knowledge of the material. Obstacles encountered when completing a project from the target material during the workshop included: designs that were too difficult to complete and the need to make changes, working under time pressure, physical fatigue and the pace of work, the scale of the mosaic, the different stages of working with clay: gluing the elements, rolling, smoothing the surface.

4. Have you had the opportunity to work with clay before?

60 answers

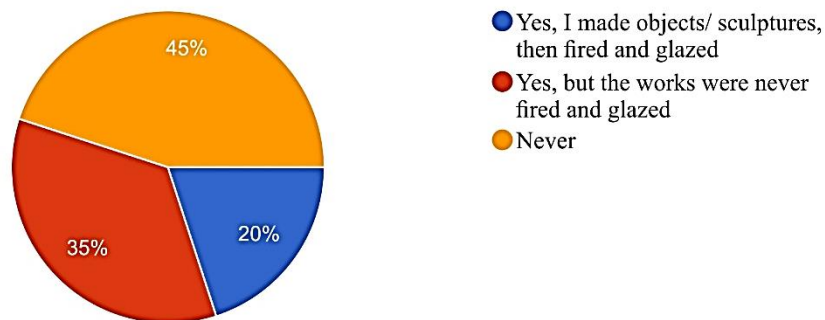


Figure 5. One of the results of the survey.

Source: prepared by Agnieszka Pluszczewicz-Fornal, graphic generated by Google Form.

23. Which design phase was the most difficult for you?

60 answers

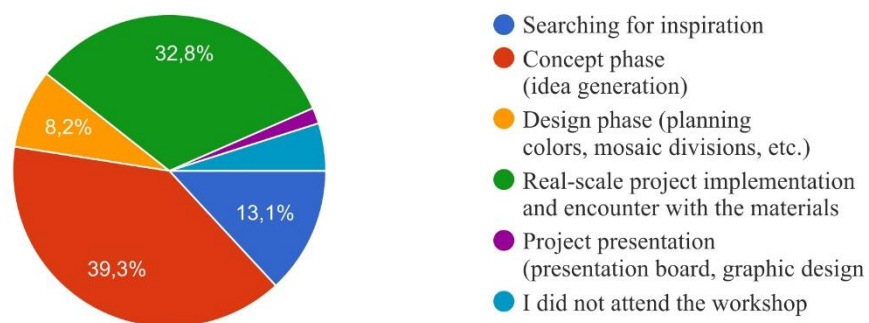


Figure 6. One of the results of the survey.

Source: prepared by Agnieszka Pluszczewicz-Fornal, graphic generated by Google Form.

As many as 67.3% of the students who participated in the workshop rated it very good and would be willing to participate in further similar activities, 30.8% rated it as a nice experience, one person described it as average. None of the people surveyed rated the workshop negatively.

The completed questionnaire survey showed that the conducted workshop and the implementation of the semester task had a great impact on the students' perception of the mosaic technique, increasing awareness and curiosity about both the technique and the material used for its implementation. As many as 66.7 per cent of the respondents estimated that the project had changed their view of the mosaic technique, 21.7 per cent of the students were unable to determine this, and only 11.7 per cent were not affected.

26. Has your perception of mosaic changed after attending the ceramics workshops and implementing the mosaic project?

60 answers

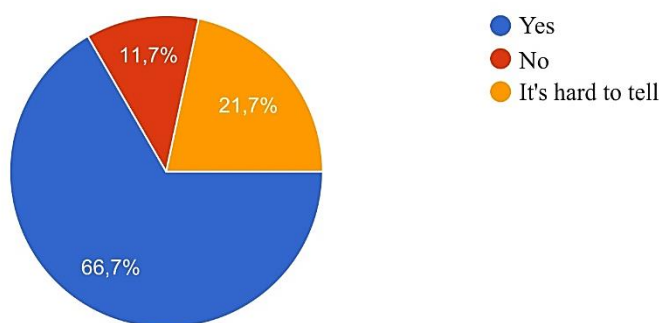


Figure 7. One of the results of the survey.

Source: prepared by Agnieszka Pluszczewicz-Fornal, graphic generated by Google Form.

In one of the open-ended questions, students were asked to define what mosaic was to them before the semester assignment. The responses showed that for the vast majority it was a somewhat forgotten art form associated with sacred and sepulchral architecture, not currently practised. Example responses: ‘little appreciated art form’, ‘nothing special’, ‘forgotten and unfashionable art’, ‘decoration’, ‘something unimportant and rather absent from the urban space’, ‘something very little known as I did not pay attention to it’. There were also results indicating a lack of familiarity with the technology: ‘I thought it was made of glass’, ‘I could not imagine how difficult it is to compose’, ‘it decorates walls or given elements, mainly in the bathroom’, ‘all my life I have been convinced that mosaic is made of glass, and I came across a new way of using clay in mosaic, which surprised me very much’, ‘not a very nice decoration for churches, now I see how much work it takes to make such works’, ‘I did not expect how long it could take to create’, ‘an old technique, I thought it was glass’. The single answers given testify to an earlier curiosity about the mosaic technique: ‘an interesting work I wanted to try’, ‘creating a mosaic was something I had always wanted to do, so it was a dream’ and surprise at the semester topic ‘I did not expect such an assignment within the class’. The students were then asked in an open-ended question how their perception of the mosaic technique had changed, the answers can be divided into groups: increased awareness, increased sensitivity, curiosity about the technique or the material. Examples of student statements:

- ‘I did not participate, however, I learned a lot during this semester. I understood the technique and will always look at it differently again’.
- ‘I now see it as something more thoughtful, not a collection of random elements as before’.
- ‘I have noticed that it is also an important architectural element with which you can achieve very interesting effects’.
- ‘I appreciate it a lot, I pay attention, I talk about it with my colleagues from the year’.

- ‘I have more awareness, I value it more and I pay attention, I educate my relatives’.
- ‘I certainly now consider it a work of art that requires a lot of time, commitment and creativity. I appreciate the mosaic much more in terms of what process takes place during the creation. When I see a mosaic in a public place, I imagine how long and hard people worked on it’.
- ‘The only thing that has changed is that I’ve grown fond of the clay and I know I’ll go there again’, she added.
- ‘I found out that a mosaic can not only appear as a decorative element, but also as a great work of art’.
- ‘I have started to appreciate the technique more and I think I will use it in some interior design project one day’.
- ‘It is a more extensive subject than I would have thought’.

28. How do you evaluate the ceramic workshops you completed at the Pottery Centre in Medynia Głogowska? (if applicable)

52 answers

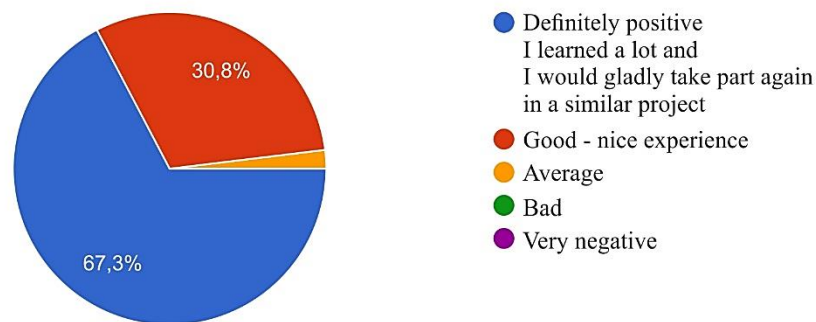


Figure 8. One of the results of the survey.

Source: prepared by Agnieszka Pluszczewicz-Fornal, graphic generated by Google Form.

9. Discussion

The activities presented in the article are innovative due to the unique combination of traditional craft techniques with modern design and teamwork methods. The didactic process was conducted holistically and culminated in the execution of the designed mosaic. The originality of the project lies in the integration of classical clay working methods into the curriculum of interior and architectural design students, allowing not only technical refinement of the workshop, but also the development of soft skills such as communication, adaptation to technological constraints and collaboration in a broad sense. There has been an increase in technical and artistic skills as a result of the workshop, allowing students to better understand

the design process from concept to completion. In addition, research has shown that the introduction of traditional ceramic techniques into students' design work enables them to explore new uses for the material in architecture. Taking into account the local and cultural context, especially the link to the Silesian region, allowed the projects to be enriched with elements of identity and tradition. And the implementation of the project itself allowed for the integration of the scientific community with the local craftsmen's centers.

Ceramic techniques are rarely used in teaching architecture, the article shows that ceramics, as part of craft traditions, can have an important role in shaping students' understanding and sensitivity to materials and design aesthetics, as well as increasing students' cultural awareness, which has not been widely explored.

The research confirmed the hypothesis that combining traditional ceramic techniques with architectural design in addition to the acquisition of artistic sensitivity supports the development of both technical and interpersonal skills in students. Lessons learned point to the need for further integration of craftsmanship with design education, which supports creativity and sensitivity to material and form. In practice, this project may inspire the introduction of similar courses in other design courses, allowing students to work with traditional techniques in modern architectural contexts. Discoveries can be used to develop educational programmes that emphasize local heritage and materials. Awareness of ceramic techniques can also contribute to a greater interest in sustainable design, including the use of local resources. In the next steps, it is planned to expand the programme to include additional classes in other traditional techniques to further enrich the educational programme. In-depth quantitative and qualitative analyses of the impact of knowledge of the techniques on students' design and interpersonal skills and the development of collaborations with local craft and art centers are also needed.

10. Conclusions

Analyzing the projects created by the students, one can notice a main division between figurative compositions and abstract compositions, flat and relief works were created.

The works included representations of:

- buildings or fragments of architecture characteristic of the city of Gliwice;
- buildings of the Silesian University of Technology and elements characteristic of the building, e.g. (Faculty of Architecture) and urban layouts;
- the logo of the Silesian University of Technology and logos of individual faculties;
- selected architectural elements and details: rhythms, textures, divisions applied in a more synthetic and general manner.

The colours of the works proposed by the students varied. Depending on the assumption, the works were both painterly and monochromatic.

Technical challenges proved to be a significant problem, including adapting the designs to the size of the molded slabs. The pottery center determined the parameters of the mosaics being created, related to the technological capabilities of the kiln. This resulted in a revision of the prepared concepts and the need to adapt the designs to the size of the molded slabs, including their appropriate thickness, i.e. to raise the relief so that firing would be possible. During the work, a problem was noted related to mixing different types of clay, which caused cracking of slabs ready for firing. The intended result of the classes was achieved with a surplus - in addition to completing the task, the students' exceptional enthusiasm, the ability to conduct observations, conversations, and reach consensus were noted. The next, final planned stage of work will include assembly in the intended location.

After the workshops, as many as 98.3% of students believe that mosaic should find its place in contemporary architecture (68.3% definitely yes, 30% rather yes), while according to 55% of students, this technique is currently underestimated (26.7% definitely underestimated, 28.3% rather underestimated), and 31.7% of respondents are not convinced. As many as 86.7% of students believe that it is justified to return to the mosaic technique in contemporary architecture, and as examples of places where it could find its place they indicated: building facades, walls, interiors of public buildings, shopping centers, public bathrooms, sports halls, schools, bus stations, underground passages, Youth Culture Centers, staircases, restaurants, and many others.

31. Do you think it is now appropriate to return to the mosaic technique?

60 answers

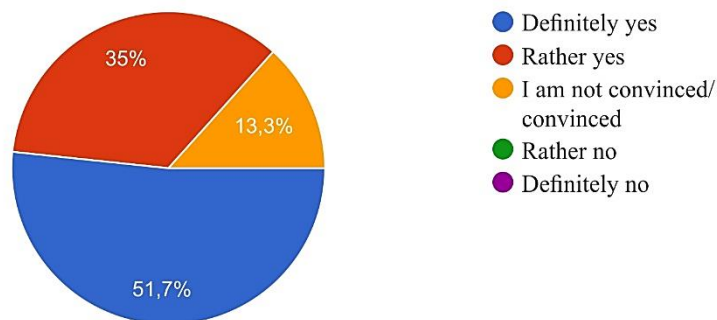


Figure 10. One of the results of the survey.

Source: prepared by Agnieszka Pluszczewicz-Fornal, graphic generated by Google Form.

11.Summary

The publication is a record of the design and implementation process important for the methodology in the didactic process. The aim of the undertaken activities was to gain a workshop and the opportunity to work in an interdisciplinary team during the implementation of mosaics. The empirical study conducted as part of this work confirms the significant impact of introducing innovative topics in the form of workshops on the development of creativity in students. The introduced topics stimulate imagination and promote a creative approach to solving design problems, which in turn increases the cognitive motivation of students. Introducing innovative topics in the form of workshops not only stimulates students' creativity, but also supports the development of a number of social and interpersonal skills. The workshop exercises presented in the article are an effective tool for learning communication, decision-making and cooperation between different participants of the design process, extremely important in the context of future professional work.

The undertaken design activities in the field of mosaics and their execution on a 1:1 scale were a new, inspiring educational experience for both young students and those conducting classes and workshops. Learning the technology and making the mosaic themselves allowed the young creators to understand the effort accompanying the creation of this type of work. As many as 66.7% of the surveyed students assessed that the undertaking changed their perspective on the mosaic technique. Thanks to the dedicated work, students were able to appreciate well-known mosaics, paying attention to their value in public space. This is confirmed by the results of the survey - 98.3% of students believe that mosaics should find their place in contemporary architecture. The presented educational activity made it possible to acquire humanistic skills, a social perspective on architecture and space in which a person should feel positive emotions. The visual side of the surroundings, the environment in which a person lives, is a very important element influencing their well-being. Cities in which we move easily thanks to clear urban layouts and architecture, we notice important places, cities with which we identify are the aspirations of every architect. Sensitivity to beauty, colours, mosaics and other results of artistic activities in urban space is of great importance in shaping the future creators of our environment.

Another important element in the didactic process was teamwork, establishing, selecting the concept and dividing responsibilities. The work required concentration and responsibility for its implementation, because a specific time was allocated for its completion. Workshop exercises allowed for the development of skills such as: communication with other creators, leaders and employees of the workshop center. They taught decision-making and cooperation between various entities involved in the design process. Students gained practical skills consisting of methods of creating a mosaic, and additionally acquired the ability to visualize their own design concepts and then present their projects and implementations. Teamwork,

learning the technology, implementing the idea and creating a mosaic on a 1:1 scale are the most important achievements of the entire didactic process. It can also be said that cooperation with various centers allowed for greater interaction of various creative environments, created the opportunity to acquire the ability to communicate with people from various creative and professional fields.

References

1. Balasiński, M., Maluga, L. (2018). Rysunek odręczny w kontekście przemian technologicznych. *Architectus*, 2(54), DOI:10.5277/arc180206.
2. Celadyn, W. (2016). Feedback in a method of architectural education. *World Trans. on Engng. and Technol. Educ.* 14, pp. 468-472.
3. Ceylan, S., Soygenis, S. (2022). Improving Architecture Students' Design Skills: A Studio Experience. *International Journal of Art & Design Education*, 41(4), DOI: 10.1111/jade.12401.
4. Jaszczuk, P. (2018). Zmiany roli przedmiotów plastycznych i metod ich nauczania w kontekście programu kształcenia architektów na Wydziale Architektury Politechniki Wrocławskiej. *Architectus* 2(54), pp. 33-48, DOI:10.5277/arc180204.
5. Kucharczyk-Brus, B., Zabawa-Krzypkowska, J. (2018). Rysunek odręczny w procesie kształcenia architektów wnętrz. *Architectus*, 2(54), DOI:10.5277/arc180203.
6. Makowska, B. (2019). Innovative methods in teaching improve the creativity of landscape architecture students, *World Transactions on Engineering and Technology Education. Cracow University of Technology*, 17(3), pp. 343-348.
7. Muszyńska, M. (2021). Technical and soft competencies in teaching architecture in the context of Industry 4.0. *World Transactions on Engineering and Technology Education*, 19(2), pp. 203-208.
8. Siomkajło, B., Łuczewska, D. (2018). Wstęp do modelowania przestrzeni – łączenie podstaw teorii kompozycji z pracą z tworzywem na Wydziale Architektury Politechniki Wrocławskiej. *Architectus*, 2(54), DOI:10.5277/arc180207.
9. Warshaw, J. (2007). *Praktyczny poradnik ceramika*. Warszawa: Arkady.
10. Wesołowski, P. (2022). Enhancing architectural engineering students' acquisition of artistic technical competences and soft skills. *Cogent Arts & Humanities*, 9, 1, 2043997, DOI: 10.1080/23311983.2022.2043997.
11. Zabawa-Krzypkowska, J., Groń, K. (2019). Architectural and artistic action meaning for public space in the city - creative teaching for students of architecture: Murals. *ICERI Proceedings, [B.m.], IATED "Academy"*, pp. 2898-2906.

12. Zabawa-Krzypkowska, J., Groń, K. (2022). Dydaktyka w praktyce. Teoria versus praktyka, działania w zakresie wystawiennictwa. *Builder Science*, vol. 305, no. 12, pp. 56-58, DOI: 10.5604/01.3001.0016.0936.
13. Żychowska, M.J. (2019). Teaching drawing to a new generation of engineers architects. World Transactions on Engineering and Technology Education. *Cracow University of Technology*, 17(1), pp. 60-65.

GEN Z VALUES AND THEIR PREFERENCES FOR A CHANGING LABOUR MARKET

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Purpose: This article is about the Gen Z generation's expected values in the labour market. The generation referred to as 'Anti-Millennials' grew up in an environment full of technology and constant access to the internet, which has influenced their expectations of the workplace. On the one hand, they have good technological skills and stand out for their ability to learn independently. However, on the other hand, they have difficulties with long-term commitment and are sometimes impatient. The article aimed to help Gen distinguish their central values towards the workplace.

Design/methodology/approach: A qualitative method was chosen to carry out the study (through short interviews). Interviews were conducted in a semi-structured format, allowing flexibility in the questions and enabling participants to share their thoughts freely. A group of 194 participants from Poland, who are at the undergraduate stage, was selected for the study. Qualitative methods such as content analysis and thematic analysis were used to analyse the data.

Findings: As the research indicates, their central workplace values are flexibility, work-life balance, teamwork, creativity and innovation. If employers want to have a loyal workforce and avoid incurring the cost of searching for new employees, they need to pay attention not only to the level of pay but also to adapt working conditions to the needs of Gen Z.

Research limitations/implications: Qualitative research has allowed us to get closer to the values Gen Z representatives mentioned to understand their expectations better.

Practical implications: Understanding the values of Gen Z will help employers in the industry sector, like other sectors of the economy, to effectively communicate and retain them in the workplace.

Social implications: The research refers to the work value Gen Z, which can help to understand this generation of workers and help them to find their way in the changing labour market.

Originality/value: This is the first research of its kind to include a group of people born between 2003 and 2006 who are just starting their careers.

Keywords: Gen Z, value, labour market, industry, Poland.

Category of the paper: research paper.

1. Introduction

Gen Z is entering the labour market in an era of rapid change with a global pandemic that has changed the rules in the world of work (Lev, T., 2022). The labour market is now intensifying not only with traditionally high staff turnover but also with the increased departure of older workers (BB generation) (Goh, Lee, 2018). The changes taking place mean that we have more and more research on Gen Z and their expectations of working life.

This generation, known as 'iGen' or 'Zoomers' (Twenge, 2017, 2023), is distinguished by their unique characteristics and preferences. In the context of this article, their most apt term is "Anti-Millennials" (Lanier, 2017). This name aptly indicates quite different expectations and values than the Millennials had. Unfortunately, GenZ entering the labour market had a lot of negative experiences, especially related to the COVID-19 pandemic, as they were one of the leading groups in society who lost their jobs at that time (e.g. tourism sector, industry) (Goh, Lee, 2018; Leung et al., 2021).

Much of the information and predictions about this generation have not been confirmed (Mărginean, 2021). Gen Z did not want to grow up quickly in a world entirely of change, and some of them are having great difficulty finding their way in a changing world (Mărginean, 2021). Gen Z grew up in a digital age in which social media platforms significantly impacted their perceptions of the world and their perception of self-worth (Haykal et al., 2024). Thanks to the world of the internet, they have much information and are afraid of constant change (Bencsik et al., 2016). Although these generations are characterised by high skills in technology and self-learning, they demonstrate low commitment to the organisation and a negligible ability to persevere in long-term tasks (Bencsik et al., 2016; Chillakuri, 2020; Lev, T. 2022).

The global pandemic and the changing rules of labour markets have accelerated the need to understand Gen Z's expectations. In this article, work values, which allow organisations to better respond to the needs and expectations of employees and enable them to address them with a working design that is both efficient and effective, have become the focus of this article (de Boer et al., 2021). Intrinsic work values refer to the actual tasks and fulfilment in doing work, including helping others or doing demanding work. External work values, on the other hand, refer to what we get out of work (rather than what we put into it) and include pay, recognition and job security (Maloni et al., 2019).

This article aims to identify the central workplace values distinguished by GenZ representatives in Poland. The following research questions will accompany such a stated objective:

RQ1: What values are important to Gen Z representatives when choosing a workplace?

RQ2: What does GenZ expect from their future workplace?

RQ3: Does gender influence GenZ representatives' preferences when choosing a workplace?

The research conducted is as relevant as it is theoretical and practical. Through an in-depth analysis of their value and impact on the professional environment, you contribute to a better understanding of labour market dynamics and how to manage talent effectively. Understanding the value of GenZ to employers will help attract (in recruitment, familiarisation with organisational culture, etc.) as well as retain talent from this generation. This research also contributes to the academic literature on Gen Z and their value in the workplace in Poland. Through the analysis of their expectations and preferences, existing research on intergenerational dynamics in the labour market will be complemented. It may also contribute to inspiring future research on the impact of technology and organisational culture on employee satisfaction with Gen Z. It also lays the groundwork for further research on the long-term impact of Gen Z values on organisations.

The structure of the paper is as follows: after introducing the research topic, the next section presents the characteristics of Generation Z employees based on the literature review. The next section concerns the materials and methods used in the empirical analysis. The fourth section presents the results of the analysis. The last section is a discussion and a set of main findings.

2. Background for analysis

2.1. Characteristics of Generation Z employees

Answers are often sought to questions about what the new generation is like and how they will behave in the labour market. The literature distinguishes seven main factors that have influenced the formation of the GenZ generation. These are: changes in demographics and life expectancy, the global culture of affluence, the technology in which this generation grew up, the demand for information, the means of education and learning, and the shift to a network of online friends (McCrindle, 2018). GenZ representatives are called 'digital natives' (Prensky, 2001) who speak a specific digital language in the workplace (Bencsik et al., 2016; Parks, 2020). The main characteristics of this generation are: responsive, pragmatic, seeking continuous and immediate interaction, consider themselves experts with technological skills, have high expectations of technology, strive for independent learning and are comfortable in digital and virtual environments (they have been using technology since childhood) (Chillakuri, 2020; Racolța-Paina, Irini, 2021; Lev, T.A., 2021; Lev, T., 2022). They are practical and intelligent rather than smart and like to lead because they are courageous (Bencsik et al., 2016). This generation favours innovation and rapid change (Koulopoulos, Keldsen, 2014) because they care about flexibility, creativity and a desire to experience different workplaces (Lanier, 2017; Seemiller, Grace, 2018). This is a generation that respects social diversity and seeks authenticity (Francis, Hoefel, 2018). The literature accentuates that these expectations differ

according to gender (Grow, Yang, 2018). However, other characteristics of this generation, such as honesty, decency, humour and being judgmental, cannot be forgotten either (Seemiller, Grace, 2018). It is also worth adding their tendency to be more impatient (Bencsik et al., 2016) and difficulty focusing their attention for extended periods (Titko et al., 2020). These traits are particularly externalised in their approach to meetings, gatherings, or work that requires much effort and focus. In representatives of this generation, there is also a noticeable lack of restrictions regarding the location of the workplace and the ease of accepting long geographical distances or different time zones in the work they do (Seemiller, Grace, 2018).

In adulthood, GenZ representatives value secure work and financial stability and prefer to work for large companies, often choosing the public management sector. According to research, they choose work that reflects their passions and seek informal and relaxed environments where they can have their own well-defined office space (Mărginean, 2021). Also at work, they feel the need to bond with colleagues and freely express their opinions (Mărginean, 2021). However, to engage them at work, employers must learn how to talk to them effectively and help them fit into the community and organisational culture (Bencsik et al., 2016).

In summary, Gen Z brings new values and expectations to the labour market, resulting from their unique experiences and environment. Their pragmatism, flexibility, and desire for authenticity present a challenge but also an opportunity for employers. Understanding these characteristics and adapting the organisational culture to meet the needs of Gen Z will be key to building engaged and motivated teams in the future.

2.2. Gen Z's preferences for the workplace

Gen Z's values encompass a wide range of work expectations. Research indicates that this generation pays much attention to intrinsic values like personal development and extrinsic values like job stability (de Boer et al., 2021). This generation wants to work in companies whose values match their own, and they can feel pride and fulfilment in their work (Goh, Lee, 2018). When looking for a job, Gen Z individuals analyse and learn about employer values (Zhang, Gowan, 2012).

The very first studies in the literature on GenZ accentuate that this is a generation for whom workplace flexibility is very important to help maintain work-life balance (Ozkan, Solmaz, 2015). Employees of this generation are looking for an indulgent workplace that allows for pleasure and social life during working hours (Lev, T., 2022). These are employees who expect work-life balance, teamwork, support, flexibility, commitment, creativity, innovation and a global working atmosphere (McCrindle, Fell, 2020).

For representatives of this generation, it is also important that the workplace is contemporary, uses new technologies, and can show initiative (Bencsik et al., 2016; Berge, Berge, 2019; Christensen et al., 2018). Despite this, they expect to be provided with independence and the opportunity to demonstrate entrepreneurship (Bencsik et al., 2016;

Christensen et al., 2018; Berge, Berge, 2019). Figure 1 shows a synthesised list of GenZ values and expectations identified in the literature.

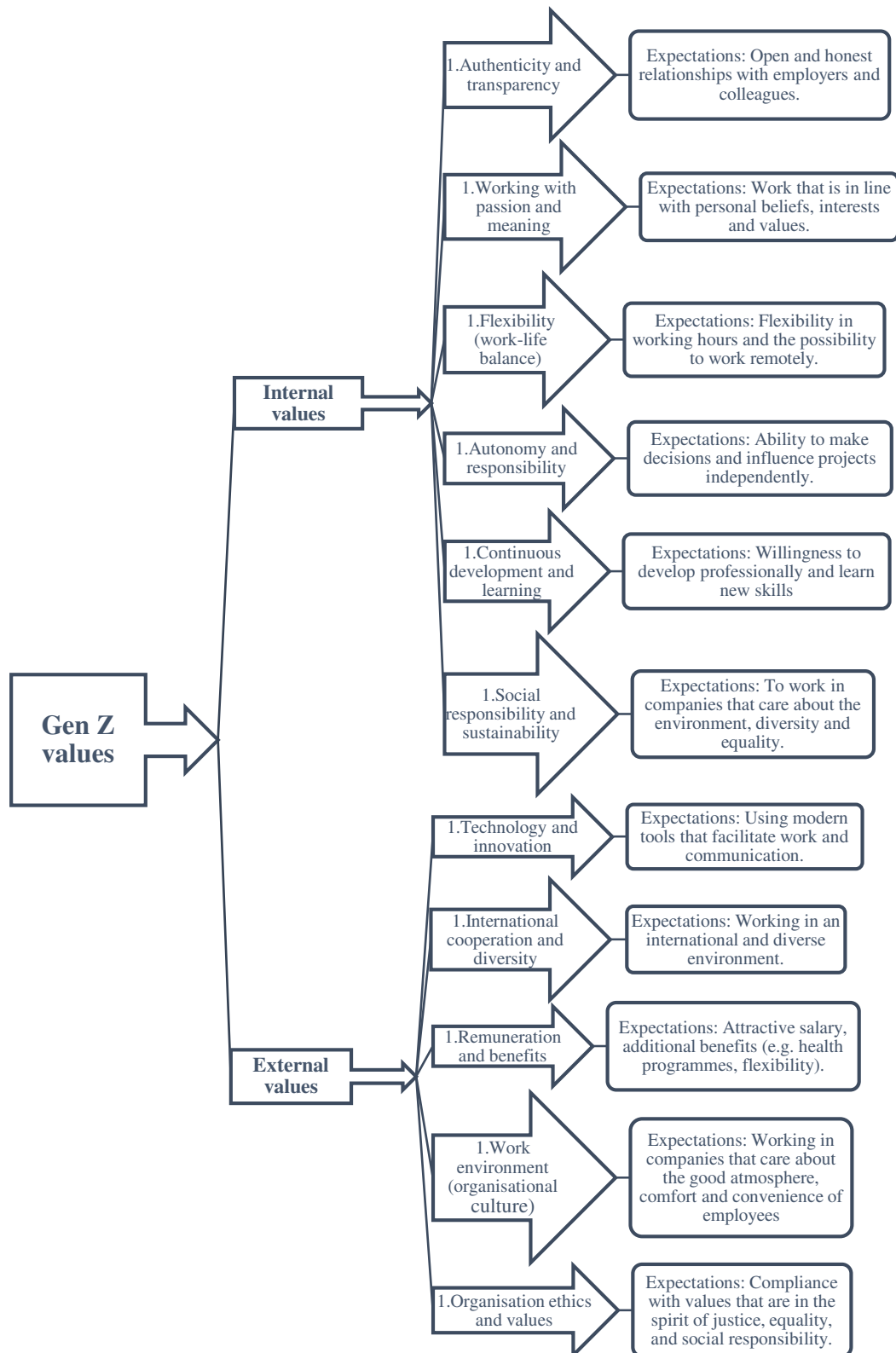


Figure 1. The central internal and external values of GenZ.

Source: own elaboration.

In summary, GenZs prioritise values that reflect their unique experiences and expectations of the labour market. Flexibility, work-life balance, and opportunities for personal development are critical to their success. Gen Z wants to work in companies that share their values, which allows them to feel pride in their work. A contemporary working environment that fosters innovation and creativity is essential to them, as well as the pursuit of independence and entrepreneurship. To successfully attract and engage representatives of this generation, employers need to adapt their approach to their expectations and create a collaborative atmosphere.

3. Materials and Methods

The literature review indicated that Generation Z is entering the labour market in a rapidly changing environment. Their unique values and expectations are crucial for organisations that want to attract and retain young employees. It also indicated what values the literature identifies as necessary for representatives of this generation. However, the literature does not indicate what values are decisive when choosing a workplace in Poland.

This study aims to identify the main values that are important to Generation Z in the context of their future workplace. It focuses on individuals born between 2003 and 2006 who are currently students and have limited work experience.

A qualitative method was chosen to carry out the study (Creswell, Poth, 2016) through short interviews with individuals from the cohort. Interviews were conducted in a semi-structured format (Kvale, Brinkmann, 2009), allowing flexibility in the questions and enabling participants to share their thoughts freely. The interviews focused on the following research questions:

- What values are most important to participants when choosing a job?
- What do they expect from their future workplace?
- How do they see their ideal workplace?

The data collected was then transcribed and analysed for the main themes and patterns. A group of 194 participants from Poland, who are at the undergraduate stage, was selected for the study. The structure of respondents by gender was as follows: 52.6% female and 47.4% male (102 females and 92 males), reflecting the structure of society by gender. Most of them did not have full-time employment, and their work experience was limited to casual work or internships.

Qualitative methods such as content analysis and thematic analysis were used to analyse the data (Creswell, Poth, 2016). This allowed the identification of critical values and GenZ expectations of jobs. The analysis is based on qualitative interviews in which participants were asked to list the values that matter to them in the workplace. The identified values were

classified into five categories and then compared regarding gender differences. Values were analysed both in terms of their number and their importance for job satisfaction. Content analysis was carried out by:

- Identification of values: Values mentioned by interview participants were identified and classified.
- Gender comparison: Differences in values between men and women in each category were explored.

Use of thematic analysis: Themes were extracted based on the most frequently mentioned values.

Content and thematic analysis of the workplace values data collected from men and women identifies significant discrepancies in the value priorities of the two groups. The results of this research may be crucial for understanding how diverse perspectives on work shape work experiences and satisfaction levels and for identifying areas where organisations can implement changes to better meet the needs of their employees, regardless of gender. These differences and their potential impact on workplace performance in the context of gender equality and organisational effectiveness will be discussed.

4. Results

First, a content analysis of the respondents by category was undertaken. Table 1 presents the results for the management category.

Table 1.
Category - Management

Value	Women	Men
Good organisation	12	-
Good manager	11	-
Social responsibility	-	5
Good governance	-	4

The results indicated that effective management and structured work organisation are essential for women's job satisfaction, with women showing a particular preference for a supportive work environment and clear task organisation. Women are more likely than men to emphasise high-quality management, which includes access to mentoring and career development opportunities. These elements are seen as critical motivators, providing them with a sense of job security and stability. Men, on the other hand, while also attaching importance to

organisational goals and work structure, are more focused on issues related to social responsibility and ethical standards of organisational performance. Such values can be an essential element of their commitment and motivation to work.

Regarding the impact of values on job satisfaction, women prefer a work environment that provides strong structural support and enables them to complete tasks efficiently based on a clearly defined work organisation. Conversely, for men, job satisfaction appears to be more dependent on consistency with organisational goals, the ability to meet social responsibility challenges and the achievement of measurable results. Notably, women show a more substantial interest in interpersonal relationships and work organisation, while men are more likely to emphasise the importance of innovation and operational efficiency as key motivational determinants.

These differences in values may be due to the different social and cultural expectations that shape the professional attitudes of the two genders and influence their different perceptions of the role of work in their personal and social lives.

The second category subjected to content analysis was working conditions. These results are shown in Table 2.

Table 2.
Category - Working conditions

Value	Women	Men
Good atmosphere	27	16
Fair pay	23	19
Balance between life and work	14	-
Flexibility	-	10

Values related to job satisfaction vary by gender, which has important implications for organisations in human resource management. Women strongly prefer a work environment that fosters collaboration and emotional support. Their job satisfaction is closely linked to the balance between remuneration and responsibilities and to a work atmosphere that enables positive interactions and interaction with colleagues. In line with these values, women particularly value an environment that offers the flexibility to better combine work and personal responsibilities, including time for family. In addition, job stability and opportunities for career development, including training programmes and promotion, are crucial to their long-term job satisfaction. These values indicate that women not only expect adequate remuneration for their work but also seek a work environment conducive to their personal and professional development.

Men, while also valuing fair remuneration for their work, are more focused on flexibility and work standards. For them, mental well-being in the workplace is just as important as remuneration, which can manifest itself in a preference to avoid excessive tension and stress. Men also value an excellent working atmosphere, although, compared to women, they do not attribute such a central role to it. Instead, they are more concerned with flexibility in working hours, allowing for better work-life balance control. Additionally, men value high professional standards and professionalism in their tasks, which is an essential element of their sense of satisfaction and professional value.

Comparing the preferences of the two groups, it can be seen that both women and men value fair pay and a positive working atmosphere. However, women show a stronger work-life balance expectation and job satisfaction depends more on emotional and organisational support at work. Conversely, men place more emphasis on flexibility and standards of professionalism, which, in their case, is an important motivational factor.

From an organisational perspective, these values differences should be considered when designing human resource management policies. Organisations should strive to create a working environment that offers fair remuneration and promotes work-life balance, especially in the context of women's expectations. Creating such conditions will foster higher job satisfaction and employee engagement, regardless of gender.

The third step of content analysis was analyzing the workplace relationships category. The results are shown in Table 3.

Table 3.
Workplace relationships category

Value	Women	Men
Estimate	27	9
Good relations with the team	24	18

Professional relationships based on mutual respect are a crucial element affecting women's job satisfaction. Women particularly emphasise the importance of being treated with dignity, which they see as the foundation of a positive working atmosphere. A supportive environment conducive to building positive interpersonal relationships significantly increases job satisfaction. Women expect to be treated respectfully, contributing to their sense of security and value in the organisation. Therefore, Good interpersonal relationships and a sense of fairness and tolerance are essential elements of job satisfaction.

Men also value interpersonal relationships, but their approach may be more pragmatic and oriented towards collaborative team effectiveness. Although respect is essential for men, the more functional side of interaction, related to achieving organisational goals and team effectiveness, plays a key role. For them, interpersonal relationships are meaningful but do not have such a dominant impact on job satisfaction as for women.

Comparing these differences, both groups recognise respect as a fundamental element of good workplace relationships, but women place more emphasis on values such as tolerance, fairness and mutual support. While valuing respect, men focus more on collaborative effectiveness and achieving common goals within the team.

From an organisational perspective, these findings suggest that it is necessary to promote team-building programmes and provide interpersonal communication training that addresses employees' diverse needs and expectations. Creating an environment that promotes respect, tolerance and fairness, especially for women, while prioritising collaborative effectiveness for men can significantly improve job satisfaction in organisations.

The next step of content analysis was the analysis of personality category. Table 4 shows results of this analysis.

Table 4.
Category - personality

Value	Women	Men
Professional development	40	17
Inspiring work	12	9

Women at work strive for self-fulfilment and seek inspiration, treating professional development as an integral part of their job satisfaction. For them, work should motivate, stimulate creativity, and enable self-expression. This approach is linked to their pursuit of personal and professional goals beyond work's purely functional aspects. While equally committed to professional development, men focus more on achieving specific professional goals, which are often more measurable and results-oriented. Although they also value development, their career goals are more oriented towards individual success and achieving specific tasks, which may lead to differences in career attitudes compared to women.

The comparative analysis in the fourth category reveals that both groups value career development. However, women focus more on personal fulfilment and finding inspiration at work, while men emphasise individualism and achieving specific results. Women clearly emphasise the need for work that not only provides them with opportunities for development but also a source of inspiration, which can significantly impact their overall job satisfaction.

In terms of impact on job satisfaction, organisations should offer appropriate career development opportunities and mentoring programmes to employees of both genders that consider the differences in motivations and needs of the two groups. Women may feel a more vital need for inspiration and self-fulfilment at work, which should be considered when designing organisational career development policies. Providing such opportunities promotes job satisfaction and increases employee commitment and loyalty.

The fifth category, other values, was the subject of the content analysis. The results of the analysis of values other than the four indicated so far are shown in Table 5.

Table 5.

Category - other work values

Value	Women	Men
Corporate image	13	-
Own business	-	9

Women show a more substantial interest in working for organisations with a positive image, linked to their preference for social and ethical values in the workplace. For women, a company's image that reflects its commitment to social responsibility, sustainability and caring relationships with its employees is crucial. Such values can significantly influence their career decisions, as working for an organisation with a positive image can foster a sense of professional satisfaction and fulfilment.

In contrast to women, men are more likely to perceive entrepreneurship as a preferred career path, placing more importance on autonomy, professional risk, and the ability to shape their own careers. Entrepreneurship, understood as running one's own business or being active within more independent professional structures, is often, for men, the key element that defines their career aspirations.

A comparison of preferences in the fifth category shows that women are more likely to choose organisations with a positive image, which may be an important factor influencing their career satisfaction. Conversely, men show more interest in owning their own businesses, which is in line with their desire to be independent and achieve their own career goals.

Understanding corporate image values is critical for organisations that want to attract and retain talent, especially women. Organisations that effectively communicate their positive image can increase their attractiveness in the labour market, contributing to higher employee satisfaction and engagement.

Differences in value priorities between women and men significantly impact their job satisfaction. Women place more emphasis on interpersonal relationships, work atmosphere, and organisational values, while men are more likely to focus on aspects related to social responsibility and entrepreneurship. Understanding these differences is crucial for organisations seeking to improve employee satisfaction and optimise the working environment, considering both groups' specific needs.

5. Tapping into research findings

Differences in value priorities between men and women significantly impact their job satisfaction, and understanding these differences is critical for organisations seeking to increase employee engagement and loyalty. In order to effectively align their HR strategies with the needs of both genders, organisations should take the following actions:

- Invest in managerial training to improve management skills and employee support to increase management effectiveness and team satisfaction.
- Promoting work-life balance, especially for women, with greater emphasis on flexibility and the ability to balance work and life responsibilities.
- Building interpersonal solid relationships through team-building programmes and communication training will help create a positive working atmosphere that fosters collaboration and engagement.
- Offering career development opportunities that consider the differing needs of women and men, including mentoring programmes that support self-realisation and achieving specific career goals.
- Paying attention to the company's image is particularly important for women. They are more likely to choose organisations with a positive image, which affects their satisfaction and loyalty.
- Creating a supportive working atmosphere by fostering a culture of respect, cooperation, and tolerance within the team, which improves interpersonal relationships and fosters trust.
- Offering mentoring and training programmes to help employees develop their skills, which not only attracts talent but also retains valuable employees.
- A balanced working model that allows for flexible working hours and remote working options is significant for women, allowing them to better combine work and private life responsibilities.
- Transparency in remuneration allows employees to understand the remuneration structure and increases the sense of fairness within the organisation, contributing to higher job satisfaction.

Understanding the values that women and men ascribe to different aspects of work allows organisations to better align their human resource management strategies with their needs. By doing so, organisations can not only increase the job satisfaction of their employees but also strengthen their commitment and loyalty, which will contribute to organisational success in the long term.

6. Discussion and conclusions

Generation Z employees pay attention to intrinsic values such as job satisfaction and personal development and extrinsic values such as remuneration, recognition and job security. Gen Z prefers working environments that foster collaboration, creativity and innovation. They expect employers to be able to communicate effectively with them and to support them in integrating into the organisational culture. Because of their characteristic need for immediacy and impatience, organisations need to adapt their approach to managing young workers in order to engage them effectively. The differences in value perceptions between men and women are also an essential aspect employers should consider in their recruitment and management strategies. Gen Z is a generation that values authenticity, diversity and continuous development, which is crucial for the future of the labour market.

Generation Z is entering the labour market during major social and technological transformations (Bencsik et al., 2016; de Boer et al., 2021; Haykal et al., 2024). Gen Z is the first truly global generation, growing up in an uncertain and complex environment that determines their view of work, learning and the world (Bencsik et al., 2016). The overriding value for this generation is work-life balance, as confirmed by research (Berge, Berge, 2019; Lev, T.A., 2021; Lev, T., 2022). In the workplace context, the value of employee-organisational fit encompasses multiple dimensions, including person-organisational fit, person-supervisor fit, person-job fit, and person-occupation fit, which is still poorly researched (Maloni et al., 2019). The lack of this match can negatively affect attitudes towards work and job satisfaction (Maloni et al., 2019).

Although research interest in Generation Z is growing, many areas still require further research. We know this generation's expectations of work, but it is worth exploring how long-term employment affects their values and attitudes. Understanding these aspects will help employers better tailor their talent management strategies and create a work environment conducive to young employees.

In terms of professional values, there are clear differences between women and men that significantly impact their job satisfaction. Women place more emphasis on aspects related to interpersonal relationships and the atmosphere in the workplace, while men are more likely to indicate the importance of social responsibility and entrepreneurship. Understanding these differences is crucial for organisations that want to improve the satisfaction of their employees. The analysis pointed to the need for employers to tailor their offerings to the specific needs of both genders, which can result in better outcomes for both employees and organisations. This is particularly relevant for sectors such as industry, where men dominate the workforce and the role of women is increasing every year.

The study's results show significant differences in the career priorities of women and men. Women show a stronger interest in values related to interpersonal relationships and work-life balance, while men focus on work flexibility and social responsibility. These differences may be relevant for the design of HR policies that take into account the specific needs of both genders in terms of work organisation.

In the context of interpersonal relationships, there are some universal values for both men and women, but also differences in what they consider most important. For women, emotional connections, support, and understanding are often key. They value communication, closeness in relationships, security, and stability. Men, on the other hand, often place more emphasis on independence, achievement and recognition. For them, aspects related to respect and partnership are also important, as well as the opportunity to express themselves in terms of personal ambitions. Of course, these differences are not absolute and depend much on each person's experiences and values. Shared communication and understanding of the needs of both parties are key to building healthy relationships.

The data collected provides valuable information about employees' expectations of the workplace. Organisations should consider these differences when developing human resource management strategies and employment policies. Adapting the work environment to meet different needs can lead to higher job satisfaction and greater engagement for all employees. In the context of future research, further research is recommended to understand better the impact of these differences on long-term employee retention and engagement.



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References

1. Bencsik, A., Juhász, T., Dr. Horvath-Csikos, G. (2016). Y and Z Generations at Workplaces. *Journal of Competitiveness*, 6, 90-106. <https://doi.org/10.7441/joc.2016.03.06>
2. Berge, Z., Berge, M. (2019). The Economic ABCs of Educating and Training Generations X, Y, and Z. *Performance Improvement*, 58, 44-53. <https://doi.org/10.1002/pfi.21864>
3. Chillakuri, B. (2020). Understanding Generation Z expectations for effective onboarding. *Journal of Organizational Change Management, ahead-of-print*. <https://doi.org/10.1108/JOCM-02-2020-0058>

4. Christensen, S., Wilson, B., Edelman, L. (2018). Can I relate? A review and guide for nurse managers in leading generations. *Journal of Nursing Management*, 26. <https://doi.org/10.1111/jonm.12601>
5. Creswell, J.W., Poth, C.N. (2016). *Qualitative Inquiry and Research Design: Choosing Among Five Approaches*. SAGE Publications. <https://books.google.pl/books?id=DLbBDQAAQBAJ>
6. de Boer, P., Bordoloi, P., Dallmann, J., Hengshen, L. (2021). *Generation Z work values: A cross-national analysis*.
7. Francis, T., Hoefel, F. (2018). *'True Gen': Generation Z and its implications for companies*. McKinsey & Company.
8. Goh, E., Lee, C. (2018). A workforce to be reckoned with: The emerging pivotal Generation Z hospitality workforce. *International Journal of Hospitality Management*. <https://api.semanticscholar.org/CorpusID:53646785>
9. Grow, J., Yang, S. (2018). Generation-Z Enters the Advertising Workplace: Expectations Through a Gendered Lens. *Journal of Advertising Education*, 22, 7-22. <https://doi.org/10.1177/1098048218768595>
10. Haykal, D., Cartier, H., Kroumpouzou, G. (2024). Educational strategies to combat harmful cosmetic dermatology trends in Generations Alpha and Z. *Skin and Eye Diseases Part III*, 42(4), 415-419. <https://doi.org/10.1016/j.clindermatol.2024.05.004>
11. Koulopoulos, T., Keldsen, D. (2014). *The Gen Z Effect: The Six Forces Shaping the Future of Business*. Bibliomotion, Incorporated. <https://books.google.lt/books?id=b8hXBAAAQBAJ>
12. Kvale, S., Brinkmann, S. (2009). *InterViews: Learning the craft of qualitative research interviewing*. Sage Publications, Inc., pp. xviii, 354.
13. Lanier, K. (2017). 5 things HR professionals need to know about Generation Z. *Strategic HR Review*, 16, 00-00. <https://doi.org/10.1108/SHR-08-2017-0051>
14. Leung, X., Sun, J., Zhang, H., Ding, Y. (2021). How the hotel industry attracts Generation Z employees: An application of social capital theory. *Journal of Hospitality and Tourism Management*, 49, 262-269. <https://doi.org/10.1016/j.jhtm.2021.09.021>
15. Lev, T. (2022). Who is Afraid of Generation Z? The Intergenerational Gap Affecting the World of Work Post-COVID-19 Era. *Logos Universality Mentality Education Novelty: Social Sciences*, 11, 01-17. <https://doi.org/10.18662/lumenss/11.1/59>
16. Lev, T.A. (2021). Generation Z: characteristics and challenges to entering the world of work. *CrossCultural Management Journal*, 1, 107-115.
17. Maloni, M., Hiatt, M., Campbell, S. (2019). Understanding the work values of Gen Z business students. *The International Journal of Management Education*, 17, 100320. <https://doi.org/10.1016/j.ijme.2019.100320>
18. Mărginean, A. (2021). Gen Z Perceptions and Expectations upon Entering the Workforce. *European Review Of Applied Sociology*, 14, 20-30. <https://doi.org/10.1515/eras-2021-0003>

19. McCrindle, M. (2018). *The ABC of XYZ: Understanding the Global Generations*.
20. McCrindle, M., Fell, A. (2020). *Understanding the Impact of COVID-19 on the Emerging Generations*.
21. Ozkan, M., Solmaz, B. (2015). The Changing Face of the Employees - Generation Z and Their Perceptions of Work (A Study Applied to University Students). *4th World Conference on Business, Economics and Management (WCBEM-2015)*, 26, 476-483. [https://doi.org/10.1016/S2212-5671\(15\)00876-X](https://doi.org/10.1016/S2212-5671(15)00876-X)
22. Parks, E. (2020). Listening Across the Ages: Measuring Generational Listening Differences with the LCI-R. *International Journal of Listening*, 36, 1-11. <https://doi.org/10.1080/10904018.2020.1748503>
23. Prensky, M. (2001). Digital Natives, Digital Immigrants Part 1. *On the Horizon*, 9(5), 1-6. <https://doi.org/10.1108/10748120110424816>
24. Racolța-Paina, N., Irini, R. (2021). Generation Z in the Workplace through the Lenses of Human Resource Professionals - A Qualitative Study. *Quality - Access to Success*, 22, 78-85.
25. Seemiller, C., Grace, M. (2018). *Generation Z: A Century in the Making*. Taylor & Francis. https://books.google.lt/books?id=v_d1DwAAQBAJ
26. Titko, J., Svirina, A., Skvarciany, V., Shina, I. (2020). Values of Young Employees: Z-Generation Perception. *Verslas Teorija Ir Praktika*, 21, 10-17. <https://doi.org/10.3846/btp.2020.11166>
27. Twenge, J.M. (2017). *iGen: Why Today's Super-Connected Kids Are Growing Up Less Rebellious, More Tolerant, Less Happy-and Completely Unprepared for Adulthood-and What That Means for the Rest of Us*. Atria Books. <https://books.google.lt/books?id=HiKaDQAAQBAJ>
28. Twenge, J.M. (2023). *Generations: the Real Differences Between Gen Z, Millennials, Gen X, Boomers, and Silents-And What They Mean for America's Future*. Atria Books. <https://books.google.lt/books?id=zsV0EAAAQBAJ>
29. Zhang, L., Gowan, M. (2012). Corporate Social Responsibility, Applicants' Individual Traits, and Organizational Attraction: A Person-Organization Fit Perspective. *Journal of Business and Psychology*, 27. <https://doi.org/10.1007/s10869-011-9250-5>

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