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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 20 papers.

The papers presented in the number concentrate on many topics connected with organization and management. There are in the number papers about resource management, human resource management, quality management, the usage of AI in management, logistics, project management, service management, sustainable development, industrial management, ESG reporting, health care management and environmental management.

Radosław Wolniak

SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2024
ORGANIZATION AND MANAGEMENT SERIES NO. 214

INTANGIBLE CAPITAL OF THE ORGANIZATION AS A MANAGEMENT RESOURCE IN THE DIGITAL AGE

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Purpose: The paper aims to explore how digital transformation is reshaping the management of intangible capital within organizations. It seeks to analyze the intellectual, social, and psychological capital roles as critical resources for ensuring organizational effectiveness, innovation, and sustainability in a dynamic digital economy.
Design/methodology/approach: The paper employs a conceptual approach, synthesizing insights from recent theoretical frameworks and empirical studies to examine the interplay between digital transformation and intangible capital management. Key intellectual, social, and psychological capital elements are analyzed in the context of technological innovation, organizational processes, and employee behavior, highlighting their impact on strategic sustainability.
Findings: The study reveals that digital transformation fundamentally alters the management and utilization of intangible capital. Intellectual capital benefits from enhanced knowledge-sharing platforms, automation, and artificial intelligence, which optimize organizational learning and innovation. Social capital evolves through new digital communication tools that strengthen collaboration within and beyond organizational boundaries. Psychological capital gains importance as a resource for managing stress, fostering resilience, and maintaining employee motivation amid rapid technological changes.
Research limitations/implications: The conceptual nature of the research limits its empirical validation, suggesting the need for future studies to explore quantitative and qualitative evidence. Further research could investigate sector-specific dynamics of intangible capital management and the long-term effects of digital transformation on organizational competitiveness.
Practical implications: The findings highlight actionable organizational strategies, such as investing in digital tools to enhance knowledge management, fostering digital communication to build social networks, and prioritizing employee well-being to sustain psychological capital. These practices can significantly improve productivity, innovation, and adaptability in the digital era.
Social implications: By enhancing the effective management of intangible capital, organizations can foster inclusive and collaborative environments that benefit society. Strengthening intellectual and social capital contributes to community development, while

prioritizing psychological capital improves workplace well-being, addressing broader social challenges like stress and mental health.
Originality/value: The paper comprehensively examines intangible capital as a management resource in the digital age, integrating insights into intellectual, social, and psychological capital. It offers valuable guidance for academics and practitioners aiming to optimize organizational resources in the context of technological transformation.
Keywords: management, intangible capital, intellectual capital, social capital, psychological capital.
Category of the paper: Research paper.

Introduction

In globalization and the rapid digitalization of economies, where traditional tangible assets are no longer the only source of competitive advantage, organizations must focus on effectively using resources such as knowledge, intellectual property, brands, reputation, and other intangible assets. Such resources have become the basis for creating innovations that increase efficiency and are decisive factors for achieving organizational development in global competition.

In the process of digital transformation, organizations face new challenges and opportunities. (Kuzior et al., 2023) A high level of technological integration makes it much easier to preserve, develop, and transfer intangible capital but simultaneously creates the need to constantly update tools for managing such assets. Therefore, it is essential for organizations not only to own intangible capital but also to manage it effectively to maintain their competitiveness in the market.

Intellectual, social, and psychological capital is essential in the modern digital environment. Intellectual capital (Bellucci et al., 2020) has become a key factor in innovation and organizational growth, including knowledge and experience and the ability to adapt to new technologies quickly. Social capital (Spottswood et al., 2020) is defined by relationships, partnerships, and shared values, essential for creating effective collaborative networks. Meanwhile, psychological capital (Newman et al., 2014) influences employee motivation and emotional resilience, which is crucial in ensuring high productivity in the face of constant change and stress.

Thus, effective management of intangible capital in the digital age requires a comprehensive approach integrating technological innovation, knowledge management, human resource development, and building strong social ties (Eisfeldt et al., 2014; Crouzet et al., 2022). The article is devoted to analyzing key issues of intangible capital management and the relationship between intellectual, social, and psychological capital that influence organizations' strategy, innovation, and effectiveness in the modern digital environment.

Methods

The article used a conceptual approach that includes theoretical and empirical research methods to achieve the set goal. Theoretical methods included analyzing and synthesizing modern scientific techniques and systematizing digital transformation and intangible asset management literature. This made it possible to build a conceptual basis for the study, identify key categories, and establish relationships between them.

Empirical methods involve content analysis of secondary data on implementing technological innovations in management processes. Particular attention was paid to qualitative analysis of the impact of intellectual, social, and psychological capital on the strategic sustainability of organizations. Methods of generalization of practical experience were used to confirm the conclusions obtained.

The choice of these methods is justified by the need to integrate an interdisciplinary approach to take into account the complexity of the research issues and ensure a comprehensive study of the impact of digital transformation on the intangible capital of organizations. This made it possible to establish theoretical foundations for increasing management efficiency in the context of technological change.

Results

1. Intellectual capital in the digital age

The value of intellectual capital goes far beyond traditional material and financial assets, as it is the driving force for the development of organizations in a globalized and technologically advanced world. Knowledge and competencies, not just physical or financial resources, determine success in a dynamic and competitive environment.

Intellectual capital is an intangible asset of an organization that includes knowledge, skills, experience, the innovative potential of employees, and other invisible resources that ensure the creation of added value. (Quintero-Quintero et al., 2020) This type of capital is essential in today's digital transformation and globalization, when the value of an organization increasingly depends on its ability to generate new ideas, adapt to change, and innovate.

In addition, intellectual capital creates a platform for collaboration between people, technology, and processes, allowing organizations to improve productivity, strengthen ties with customers and partners, and increase their competitiveness.

Intellectual capital is the sum of human, structural, and customer capital that together form the basis for an organization's innovative development and strategic sustainability (Kuzior et al., 2022; Goldin, 2024; Aramburu et al., 2011; Swart et al., 2016). Figure 1 presents the main components of intellectual capital that interact with each other and form the basis for creative development and strategic sustainability.

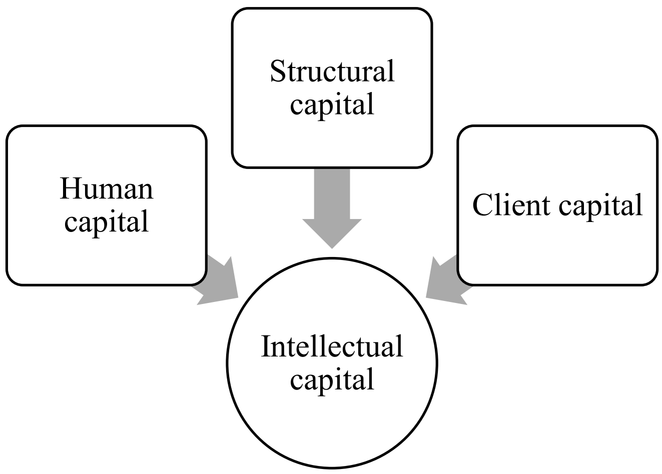

Figure 1. Components of intellectual capital.

Figure 1 demonstrates that an organization's intellectual capital is the result of the synergy of three main components: human, structural, and customer.

Human capital includes employees' knowledge, skills, experience, and creativity, ensuring the organization's innovative potential. Human capital is a source of ideas, innovations, and strategic initiatives. In the modern digital environment, the role of human capital is growing because employees not only perform assigned tasks but also actively contribute to the transformation of the business.

Structural capital covers internal processes, organizational culture, technologies, and the knowledge base that creates conditions for practical work and implementing innovations. Such an environment supports human capital and allows you to maximize its potential.

Customer capital reflects the value of relationships with customers and partners and the organization's reputation in the market. Customer capital determines the company's ability to attract, retain, and expand its customer base, especially in conditions of high competition.

All elements interact and complement each other, strengthening the organization's ability to adapt to change, generate new ideas, and achieve strategic goals. Intellectual capital arises as a result of such interaction and provides the basis for the development and competitive advantages of the organization.

Intellectual capital is vital to organizations' successful adaptation to digital transformation conditions (Bamel et al., 2020; Pew Tan et al., 2007). In today's business environment, where digital technologies rapidly change the game's rules, knowledge, innovative potential, and strategic resources become the basis of competitive advantages.

First, intellectual capital contributes to the implementation of new technologies and processes. Thanks to human capital, which includes skills, creativity, and the ability to learn, organizations can successfully adapt to using advanced digital tools such as artificial intelligence, big data, and automation.

Secondly, structural capital in the form of innovative infrastructure, databases, and technology platforms allows an organization to integrate digital solutions into its business processes. This approach provides increased efficiency, speed of decision-making, and flexibility in response to changes in the market environment.

Thirdly, customer capital becomes essential for strengthening the organization's position in digital markets. Building trusting relationships with customers and partners and using their data to personalize products and services helps increase loyalty and create additional value.

In general, intellectual capital provides organizations with the opportunity not only to adapt to digital changes but also to be their driver (Paoloni et al., 2020; Ahmed et al., 2019). By integrating human, structural, and customer capital, organizations can create innovative products, optimize business processes, strengthen their reputation, and ensure sustainable development in the conditions of digital transformation.

2. Social capital in the digital age

Social capital is an intangible asset encompassing the social ties, norms, values, trust, and interactions within a community or organization. It enables effective communication, coordination, and cooperation between social or professional group members, contributing to achieving common goals (Portes, 2024). Social capital goes beyond material or intellectual resources, as its basis is relationships between people. It includes formal networks (e.g., professional associations, organizations, or collectives) and informal ones (personal relationships, friendships).

Figure 2 visualizes the main components of social capital, namely trust, social ties, and norms and values, which are essential elements of interaction between individuals in society (Chetty et al., 2022a, 2022b). The interaction of such components forms social capital that supports the development of communities and organizations.

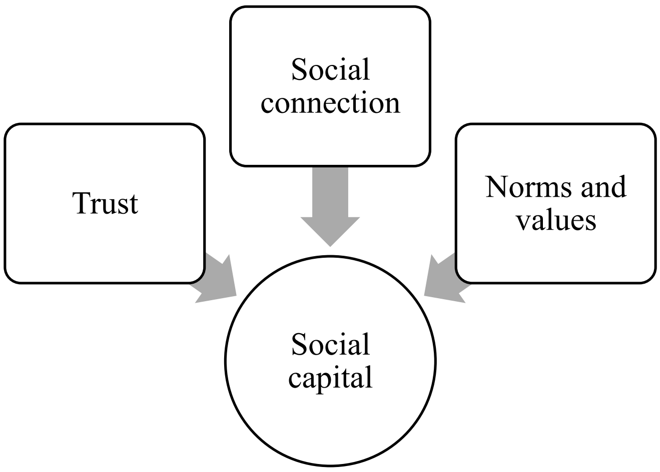

Figure 2. Components of social capital.

Social capital includes several main components that interact with each other to ensure practical cooperation in society and business. One of the essential components is trust, which provides stability and transparency in relationships, reduces the risk of conflicts, and promotes an open exchange of ideas and resources. Another critical component is social ties, which form a network of relationships between individuals and are the basis for cooperation. Social relations can be horizontal, between equal group members, and vertical, between subordinates and managers. Developed social ties contribute to exchanging knowledge, experience, and support for interaction within the community. In addition, the norms and values common to community members regulate their behavior, forming the basis for practical cooperation. In a corporate environment, such norms can become part of the organizational culture and contribute to the cohesion and integrity of the team.

Social capital has taken on new forms with the spread of digital technologies. Online communities, social networks, and digital platforms have become key tools for forming and developing relationships. Digitalization has opened up several new opportunities, including quick access to resources and information, increased network interaction (globalization of relationships), and professional development and networking platforms (Filipovic et al., 2023; Boutilier, 2017). However, with the advantages come new challenges, namely the threat of superficiality of relationships due to the lack of personal interaction, the decline in trust due to information manipulation, and the need to adapt to new forms of communication.

3. Psychological capital in the digital age

Psychological capital is the psychological resources that contribute to personal development, effective performance, and success. Psychological capital is the internal qualities and strengths that allow a person to overcome difficulties, adapt to change, and maintain motivation at a high level (Luthans et al., 2017). Psychological capital is an essential factor in achieving professional and personal well-being and maintaining resilience in conditions of stress and challenges.

Figure 3 reflects the concept of psychological capital, which includes elements such as optimism, self-determination, and achievement orientation, which affect the ability of an individual to cope with difficulties, achieve goals, and maintain a positive mood in the work process (Nolzen, 2018). These components interact with each other, contribute to developing a person's internal resources, and increase their effectiveness in various areas of life.

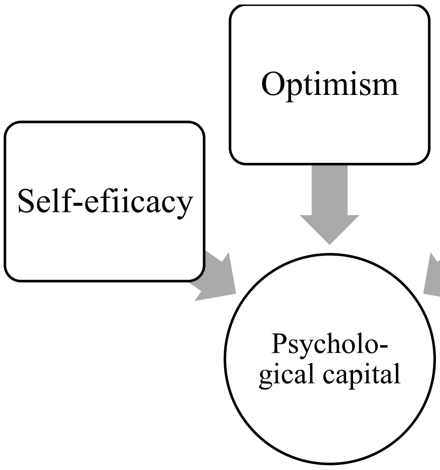

Figure 3. Components of psychological capital.

Psychological capital includes several essential components that contribute to the development of the individual and the effectiveness of his/her activities. One of these components is self-efficacy, which means confidence in one's abilities and ability to succeed in various situations. This is a motivational component that encourages a person to take active actions. Another critical component is optimism, expressed in a positive attitude toward the future and confidence that difficulties can be overcome (Datu et al., 2016). Optimism supports motivation and resilience in the process of achieving goals. In addition, achievement orientation, or result orientation, is a component of psychological capital that contributes to maintaining high productivity and efficiency through the desire to achieve ambitious goals. All components interact with each other and form the basis for successful activities and personal development.

The features of psychological capital in digitalization manifest in the interaction of various factors that affect personal development and activity effectiveness. On the one hand, digital technologies open up new opportunities for professional development. Still, on the other hand, they create pressure due to the need to constantly update knowledge and skills, which affects self-esteem and self-efficacy. People with a high level of psychological capital are more likely to adapt to new technologies and changes, which allows them to function effectively in the conditions of digitalization. However, constant information overload, the requirement to be available online, and rapid changes can lead to digital stress and burnout (Dawkins et al., 2013). Psychological capital helps to cope with challenges and maintain internal balance. In addition, optimism in the context of digital changes helps to perceive technological innovations not as threats but as opportunities for personal and professional growth. Achievement orientation is also essential in the digital environment, as it helps maintain a clear goal and strategy for achieving results, even in constant change and challenges. Thus, psychological capital is essential for adapting to a rapidly changing digital environment, allowing people to remain motivated, effective, and resilient in the face of new challenges.

4. Intangible capital as a management resource

Intellectual capital as a management resource is essential for organizations striving for development and competitiveness. Intellectual capital includes knowledge, experience, and intellectual achievements that an organization can use to improve efficiency and achieve strategic goals (Ali et al., 2021; Buenechea-Elberdin et al., 2018). Intellectual capital management consists of creating and implementing strategies that allow an organization to effectively use its knowledge, achievements, and innovations to gain competitive advantages. This approach includes the search for and preservation of necessary expertise, support, and development of the intellectual potential of employees, as well as the implementation of technologies and processes to optimize the use of knowledge in organizational activities. As a result, intellectual capital becomes not only a source of innovation but also a key factor in ensuring the long-term sustainability and effectiveness of the organization.

Social capital is a vital management resource that is actively used in management to increase productivity, strengthen corporate culture, and form an organization's development strategy. In the modern corporate environment, social capital helps create conditions for practical cooperation and innovation (Jääskeläinen et al., 2022; De Carolis et al., 2006). Building trust in teams ensures processes' transparency, reduces conflicts, and improves communication efficiency. In addition, developing social ties between employees contributes to improving internal interactions. It creates conditions for knowledge cooperation and exchange, essential for achieving high results under challenging conditions. It is also important to integrate social capital with other intangible assets, such as intellectual and psychological capital, which allows the organization to achieve development, focusing on innovation, growth, and adaptation to change. In light of modern challenges such as digitalization, decentralization of work, and the need for rapid innovation, social capital is becoming even more critical for ensuring the success of organizations. The development of social capital is the basis for building effective and competitive structures in individual organizations and society.

Psychological capital is a vital management resource that significantly impacts organizations' sustainability and effectiveness. One of the main benefits of using psychological capital is to increase the organization's resilience to external and internal changes (Witasari et al., 2020; Çavuş et al., 2015). Employees with a high level of psychological capital can adapt to change faster, effectively overcome stressful situations, and respond quickly to changes in times of crisis or industry restructuring. Investments in the development of psychological capital also significantly improve employee motivation and engagement, increasing their productivity. A positive attitude towards work, self-confidence, and a focus on achieving results help employees maintain high levels of efficiency, even under challenging conditions. This approach allows the organization to maintain stability and increase its competitiveness in the market. In addition, psychological capital is an effective tool for managing emotional risks. In high demands and stressful situations, psychological capital helps reduce stress, burnout, and negative emotions that can arise from adverse working conditions. This trend contributes to the preservation of the psycho-emotional health of employees and ensures stability in the organization. Psychological capital also helps to support innovation and creativity in the organization. Employees with a high level of psychological capital demonstrate a more remarkable ability to generate new ideas and solve complex tasks, which is a key factor for organizations that seek to maintain their competitive advantages in conditions of rapid changes in the market. Active work on developing employees' psychological capital contributes to forming a healthy corporate culture where employees feel their value, effectively interact, and work to achieve common goals. An effective corporate culture creates a positive moral climate in the company, which directly impacts the overall performance of the organization. Thus, psychological capital is a vital resource that helps to increase employees' individual productivity, ensures the organization's stability and adaptability to new conditions, and increases its competitiveness and efficiency in the long term.

Conclusions

Digital transformation is radically changing organizations' management approaches and strategies, particularly in the context of intangible capital management. The organization's intellectual, social, and psychological capital, traditionally considered essential assets for achieving strategic goals, is undergoing significant changes due to the integration of digital technologies (Kuzior et al., 2023). This trend opens up new opportunities for the effective use of these resources and creates new challenges for organizations seeking to adapt to rapid changes in the digital economy.

Digital transformation has a significant impact on the intellectual capital of the organization. Thanks to the latest digital tools and technologies, such as online learning platforms, automated knowledge management systems, and artificial intelligence, organizations can quickly adapt their development strategies and ensure continuous knowledge exchange between employees, regardless of location. At the same time, this allows for significantly reducing training costs and increasing the availability of knowledge. However, these opportunities require organizations to constantly pay attention to developing new technologies that ensure the effective use of intellectual capital.

The changes brought by digital transformation also affect the social capital of organizations. The introduction of digital communication tools allows new interaction between employees, partners, and customers (Shvindina et al., 2023). Collaboration platforms, social networks, and real-time technologies significantly improve team interaction and ensure the effective exchange of information and ideas. They also support corporate culture, helping to maintain communication between employees, even when they work remotely. Such opportunities allow organizations not only to integrate their internal resources but also to strengthen ties with external partners and customers, which, in turn, has a positive impact on social capital.

In turn, psychological capital becomes even more critical in the context of digital change because technologies change how employees work and interact. Digital tools used to monitor employees' moods and emotional state allow organizations to respond quickly to changes in employees' psychological state, reduce stress levels, prevent burnout, and help maintain a balance between work and personal life. Flexible working conditions and supporting employees' healthy emotional states through digital platforms and personalized development programs increase employee motivation and productivity, an essential factor for organizations striving to achieve high results in a rapidly changing market.

Thus, digital transformation significantly affects all aspects of the organization's intangible capital management (Balahurovska, 2023). It creates new opportunities for the development of intellectual capital through digital platforms and technologies, transforms social capital by providing new forms of interaction and communication, and improves psychological capital by offering tools to support employee motivation and resilience. However, with these opportunities come new challenges that require organizations not only to invest in technology but also to adapt management strategies to the conditions of the digital economy. Organizations must invest not only in technology but also in developing flexible and adaptive management approaches capable of effectively using intangible capital in an environment of constant change.

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CRISIS AS A STIMULANT OF THE RESILIENT MINDSET OF MARKET ENTITIES

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Purpose: This paper aims to explore how changes induced by crises may contribute to resilience of market entities and through this to show that crises can have creative and stimulating effects if organizations and individuals perceive them as an opportunity and can learn from them.
Design/methodology/approach: To address the research questions a critical review of literature on resilience and crisis was performed. In addition, we used results of the exploratory study that was conducted in the form of semi-structured interviews carried out with 20 managers and specialist representing diverse Polish companies. The interviews were organized in May-July 2023.
Findings: Research results indicate that a crisis is often perceived as an opportunity to develop and grow through overcoming obstacles and introducing positive changes. Crises can lead to long-term benefits, such as increased organizational agility, innovation, and competitiveness. This, however, is possible only if the organizations as well as their managers and employees are capable of learning from the experience and implementing constructive changes. This is related to possessing the resilient mindset.
Research limitations/implications: Due to exploratory and qualitative nature of the study, its results cannot be treated as representative, especially that the sample was small and participants represented mostly well established, large companies. The future research in this area could address the crisis-stimulated resilience and the resilient mindset of other entities, with particular regard to employees and consumers. Empirical studies describing real-life examples of the creation and use of resilience would be also very valuable.
Practical implications: Study offers valuable insights regarding ways of building resilience in volatile environment, through organizational change and crisis management but mostly through developing the resilient mindset. It indicates areas and particular examples of activities that help developing organizational resilience resilient mindset.
Originality/value: We have contributed to the field by adopting relatively new perspective and reframing crisis as an opportunity for growth rather than purely as a risk.
Keywords: crisis management, organizational resilience, organizational change, resilient mindset, flexibility.
Category of the paper: review and research paper.

1. Introduction

Today we all – nations, communities, companies, institutions, and individuals – operate within a dynamic and constantly shifting environment that is commonly described as VUCA (Volatile, Uncertain, Complex, and Ambiguous) and BANI (Brittle, Anxious, Nonlinear, and Incomprehensible) (Kraaijenbrink, 2022). Crises generated by and in such an environment differ in terms of their severity and frequency, and they may be a result of both huge natural disasters and small human mistakes. Even a minor or distant turbulence can cause disruptions to daily operations, let alone crises such as a COVID-19 pandemic, war in Ukraine, hurricanes in the US, Red Sea and Suez Canal disruption, or last floods in southern Poland. All of them present highly unpredictable and significant risks to an individual's or organization's ability to maintain their operations (Schaedler et al., 2022; Williams et al., 2017).

It is believed that crises destabilize functioning of all entities, regardless of their size, background, or history. And yet one can see that some companies similarly to some people are coping with the shocks better than others, and even more – they flourish by flexibly adapting to new conditions and hence gain advantages over less adaptive competitors. Some could argue that those successful 'survivors' were well-prepared, that they 'managed the crisis before it happened' (as suggested by Mitroff, Anagnos, 2001). But considering the above mentioned VUCA attributes of today's environment it seems unreasonable to expect that each organization will be ready for any danger, as it is impossible to even predict all potential forms of disruptions, let alone prepare for them. The question arises - if not (or at least not alone) preparedness, then what makes certain individuals and companies not only resistant to turbulences but also able to gain something precisely as a result of the disruption?

In organizational context, which is the main area of the current reflection, crises can take many forms, including economic, social, and environmental disruptions, each presenting distinct challenges and having diverse consequences for an organization, starting from decreased revenues, through serious interruption of operational continuity and supply chains, to significant reputational damage (Bundy et al., 2017; Coombs, 2007; Mitroff, Anagnos, 2001). Hence, crises are often perceived as inherently destructive events that confront the very core of organizational stability and threaten the organization by undermining its ability to maintain competitiveness (Bundy et al., 2017; Pearson, Clair, 1998).

Parallel to that stream of considerations, there is a growing body of studies taking a different perspective, i.e. positioning a crisis not solely as a threat but rather as a chance for learning and a catalysts of organizational growth (Boin, van Eeten, 2013; Duchek, 2020; Mokline, Ben Abdallah, 2021; Sommer et al., 2016). From this viewpoint, crises can provide opportunity to re-evaluate strategies, improve processes and structures, and even stimulate organization's development through enforced adaptation and innovation (Mitroff, 2005; Zygmunt, 2024).

Those implications of crisis are not only positive but even highly desirable as they both confirm and lead to an increased organizational resilience.

The term 'resilience' is used in a wide variety of fields, starting from engineering through psychology to strategic management and organizational behavior studies (Boin, van Eeten, 2013). But regardless of the context or discipline, the essence of resilience is relatively universal and refers to the "capability and ability of an element to return to a stable state after a disruption" (Bhamra et al., 2011, p. 5376). Wong-Parodi et al. (2015) add that resilience reflects the ability to acquire new capabilities and consequently to get stronger from the hardship. Resilience is hence related to a response to a turbulence and involves both the ability to withstand systematic discontinuities as well as the capability to adapt to new risk environments (Bhamra et al., 2011).

Considering the above it is worth exploring how crises can stimulate resilience and which factors may differentiate it. Are market entities, organizations in particular, able to adapt to new circumstances and get stronger after shocks in the same way some individuals adapt and become more robust after surviving traumatic experiences? Why certain organizations cope with crises better than others, but mostly – how they use the creative and constructive potential of crises?

Despite growing interest in resilience studies, so far researchers appear to have placed the strongest focus on building theories and definitions of resilience, while empirical research on resilient organizations remains scarce. In line with this approach, the resilience literature is predominately prescriptive and normative, presenting the desired attributes of a resilient organization and treating resilience as a means to recover from disturbances. In this paper, however, we would like to focus the discussion differently, trying to establish not (or not only) how resilience helps organizations withstand the crisis, but rather how crisis 'helps' organizations develop and build their even greater resilience. Additionally, we adopt a more comprehensive approach that integrates streams of research on crisis management, organizational change, and the development of organizational resilience, as recommended by Williams et al. (2017).

Therefore, the main goal of this paper is to explore how changes induced by crises may contribute to resilience of market entities and through this to show that crises can have creative and stimulating effects if organizations and individuals learn from them. To reach this goal we conducted an extensive literature review and we used, as a supplementary source of information, the preliminary results of exploratory research, i.e. semi-structured interviews carried out with 20 managers and specialist employed in diverse Polish companies. In both cases we sought to address the following research questions:

- How do market entities, particularly organizations, perceive crisis and its consequences? Do they consider positive outcomes of the negative events?
- What actions should be performed in reaction to crisis if market entities are to become more resilient and which they actually undertake?
- How do these actions contribute to building the 'resilient mindset'?

Through responding those questions we aim to offer deeper insight into the economic concept of resilience and add another piece to the growing body of research trying to explain how resilience is shaped in times of hardship.

The paper is structured as follows. The next section presents the main concepts regarded in the discussion based on the literature review. Then methodological solutions adopted in this study are described. In the next section selected results of interviews with managers are presented followed by the discussion and conclusions. At the end key findings are summarized along with limitations of the study and future directions of research in this area.

2. Literature Review

2.1. Resilience of market entities and the resilient mindset

As shown by Duchek (2020), there are three main perspectives on the resilience of market participants. In the first approach, resilience is presented as an ability to resist negative conditions, to recover after distractions, and return to a ‘normal’ (i.e. pre-crisis) state. The second perspective is adopted by researchers who look beyond the maintenance and restoration of that normal state and focus on the improvements in organizational capabilities resulting from surviving a crisis (Burnard, Bhamra, 2019). Finally, the third perspective incorporates the notion of anticipation when describing resilience. Scholars adopting this perspective indicate that organizational resilience involves identifying potential risks but primarily “taking proactive steps to ensure that an organization thrives in the face of adversity” (Somers, 2009, p. 13). Koronis & Ponis (2018) add to these perspectives another one (third in their presentation, but fourth considering the three mentioned above), i.e. human-based approach relevant to individual and group behavior and reflecting people’s ability to absorb crises, remain loyal and active, and rebuild relations and the social capital after disruption.

In this paper we interpret resilience broadly, i.e. considering the second, third, and even fourth approaches, to obtain a wider view on this concept. Hence, we define it as organization’s and its members ability to effectively absorb, develop situation-specific responses to, and ultimately engage in transformative activities to capitalize on disruptive surprises that potentially threaten their survival (Koronis, Ponis, 2018, p. 34; Lengnick-Hall et al., 2011, p. 244).

This perspective shifts resilience from being a static trait to a set of evolving capabilities of both, institutions and people that make them up, as well as steps that enhance their long-term viability and prosperity. Resilience is thus understood as a dynamic process that involves continuous learning, adaptation, and the ability to exploit crises as opportunities for improvement (Boin, van Eeten, 2013; Butler, 2018).

2.2. Dimensions of the resilience

The resilience explored in economic studies is a multi-dimensional concept originating from various sources that encompasses highly diversified areas typically perceived as contributing to an organization's or individual's ability to recover, adapt, and thrive in the face of adversity. Numerous studies (Boin, van Eeten, 2013; Burnard et al., 2018; Denyer, 2017; Duchek, 2020; Koronis, Ponis, 2018; Matysek-Jędrych et al., 2022; Nascimento et al., 2021; Pal et al., 2014; Rydzewski, 2024) attempt to summarize dimensions, drivers, sources, determinants and/or enablers of resilience. Regardless of the particular term used by the authors to refer to these elements, they all want to achieve similar goal, i.e. explore and present how resilience is/may be/should be generated. Sadly, the empirical works covering determinants of resilience are still relatively scarce (which surprises considering how popular the theme has become over last two decades), hence the majority of studies rely on the conceptual analyses and literature reviews.

Below we present the most commonly highlighted resilience dimensions, representing at the same time its drivers (enablers) and attributes of a resilient organization (see Giancotti, Mauro, 2020 for more detailed discussion):

- Adaptability (adaptive capacity): indicates any system's ability to adjust to a disturbance and moderate its effects, but also take advantage of any available opportunities and cope with the consequences of any system transformations, including unknown future circumstances. Organizations that are adaptable can modify their behavior and processes to fit the external environment, increasing their chances of survival and long-term success even in new, post-crisis conditions (Duchek, 2020; Gallopín, 2006).
- Agility (flexibility): refers to the speed and flexibility with which an entity can respond to unexpected events or opportunities. Agile organizations can make quick decisions and rapidly deploy resources to mitigate the impact of crises (Bouteraa, Bouaziz, 2023; Burnard, Bhamra, 2011).
- Learning and innovation: resilient entities view crises as opportunities for learning and innovation. By reflecting on past challenges and mistakes, they can improve processes, foster innovations, and prevent similar crises in the future (Boin, van Eeten, 2013; Malik, Garg, 2020).
- Resourcefulness: it is the capacity to effectively mobilize and utilize resources under stressful conditions. Resilient organizations are resourceful in finding ways to sustain operations despite disruptions (Mitroff, Anagnos, 2001).
- Robustness: refers to the ability to withstand disruptions without losing core functionality. In organizational context it is built through strong structures, processes, and systems that can endure stress and pressure (Bouteraa, Bouaziz, 2023; Lengnick-Hall et al., 2011).

- Transformability: reflects an ability to undergo fundamental changes when necessary. Those could involve a shift in business models, organizational culture, or strategic direction in response to major disruptions (Sommer et al., 2016).

This multi-dimensional character of resilience represents one of the central challenges of its studies. As stressed by Burnard et al. (2018), there is no directly observed sole element representing the organizational resilience, but rather multiple interactions and linkages between various variables that result in the resilience. It is these interactions that foster the complex ability to address discontinuities and adversity (Burnard, Bhamra, 2019).

2.3. Causes and consequences of crises

One could argue that crises make the fabric of today's volatile reality. Apparently, there has been a rise in the degree and range of challenges that threaten organizations and individuals. As crises come in highly diverse shapes and sizes, starting from phishing attacks to terrorism threats (see Pearson, Clair, 1998 and Valackiene, 2011 for a review), it is difficult to provide a general definition of a crisis. Still, from the organizational perspective we may state that a crisis is an event perceived by organization members and stakeholders as highly salient, unexpected, and potentially disruptive threat (Bundy et al., 2017).

Crises in organizations can arise from a variety of causes, both internal and external, each posing significant risks to organizational stability. Internal causes include management failures, operational inefficiencies, or technological breakdowns, while external factors often stem from economic downturns, natural disasters, political instability, military conflicts, or pandemics (Williams et al., 2017). These crises typically have immediate and destructive consequences, such as financial losses, reputational damage, and operational disruptions. For instance, economic crises can lead to reduced market demand, liquidity challenges, and workforce downsizing, while reputational crises may erode customer trust and stakeholder confidence (Bundy et al., 2017).

It is therefore no surprise that crises are commonly viewed through a negative lens. Especially since they not only disrupt current business operations but may also threaten the organization's future viability, undermining its ability to maintain long-term competitiveness in post-crisis conditions (Bundy et al., 2017; Heath, 1998; Schaedler et al., 2022). The destabilizing nature of crises is particularly evident in their ability to expose underlying weaknesses within an organization, such as inefficiencies in decision-making, rigid hierarchies, or insufficient risk management strategies (Bundy et al., 2017; Pearson, Clair, 1998). Additionally, crises can create a sense of urgency and uncertainty, which may exacerbate stress among employees and lead to poor decision-making in the face of constantly increasing pressure (Mitroff, Anagnos, 2001; Williams et al., 2017). Organizations unprepared for crises may find themselves in reactive modes, scrambling to address short-term problems rather than focusing on long-term resilience (Mitroff, 2005).

2.4. Crisis as a learning and improvement opportunity

While crises frequently have destructive effects, they also possess a creative potential that is often overlooked. Some scholars have even argued that the trauma inherent in crisis is developmental for a system, by providing individuals within the system opportunities for learning and change (Mitroff, 2005).

Firstly, a crisis acts as critical stress test that reveals organizational vulnerabilities, weaknesses, and generally areas with potential for improvement that may not be apparent during stable periods. As such the crisis can ultimately serve as a stimulus for preparing and implementing corrective measures, eliminating inefficiencies, and thus for overall organizational renewal (Duchek, 2020; Pearson, Clair, 1998). Secondly, the learning derived from crisis experiences often leads to improved decision-making, enhanced risk management, and a more agile organizational structure capable of responding to future disruptions (Bundy et al., 2017; Mitroff, 2005; Sommer et al., 2016). Moreover, crises can stimulate creative problem-solving and catalyze innovation as organizations are forced to think beyond traditional solutions to survive and thrive in a rapidly changing environment (Bhamra et al., 2011; Cheggag, Mokhlis, 2023; Duchek, 2020). This perspective reframes crises as valuable learning experiences, suggesting that they can ultimately contribute to long-term development of a market entity.

2.5. Building resilience in consequence of crisis – in search for the resilient mindset

Having mentioned negative and positive consequences of a crisis, we argue here that the actual character of those outcomes depends on the organization's performance and its attitudes during crisis. In particular, resilience as a potential positive outcome of a threatening event, is determined by the entity's behaviors regarding how it allocates, transforms, and acquires resources, as well as by the key factor(s) that moderate those behaviors during crisis. This transformative potential of a crisis is revealed when organizations approach it with the right mindset, i.e. when they view a threat as an opportunity to foster resilience and build adaptive capacities, rather than only focusing on mitigating damage (Boin, van Eeten, 2013; Duchek, 2020).

The critical aspects of this specific mindset are willingness and ability to change. Sawalha (2024) provides data indicating that the absence of change can be detrimental to a company and can result in numerous deficiencies, leading to organization vulnerability to crisis and incapability to resist any adversities. Denyer (2017) stresses that "organizational resilience involves changing before the cost of not changing becomes too great" (p. 16), which requires learning to do new things by changing underlying values and assumptions, creative problem solving, innovation and learning.

Another important form of shaping the right, i.e. resilient mindset is crisis management. It refers to the systematic process of addressing unexpected and potentially disruptive events that threaten operational stability of an organization or community's (Mitroff et al., 1987; Rak et al., 2022). Conceptually crisis management is based on the idea that disruptive events require prompt and strategic interventions to mitigate harm as well as proactive planning and post-crisis adaptation (James et al., 2011; Mitroff et al., 1987). At the core of this concept lies the assumption that organizations are able to anticipate crises through risk assessment and to develop plans helping them reduce their vulnerability (Coombs, 2015; Fedynets, 2023).

Table 1 summarizes the list of critical areas and forms of developing resilience during crises, originating e.g., in crisis management and organizational change frameworks.

Table 1.
Areas and methods of building resilience in times of crisis

Area	Resilience-building actions	Description
Leadership and Decision-Making	Agile Governance	Implementing flexible governance structures that can adapt to changing circumstances
	Decentralized Decision-Making	Encouraging leadership at multiple levels and empowering local teams to make decisions quickly when crises unfold; reducing bureaucratic bottlenecks
	Resilient Leadership Training	Investing in leadership development programs that focus on emotional intelligence, decision-making under pressure, and crisis management skills
Organizational Culture & Learning	Feedback Loops	Establishing mechanisms for continuous feedback from employees and stakeholders to drive ongoing improvement
	Inclusive approach and Psychological Safety	Creating a culture where employees feel encouraged and safe to report issues and offer innovative solutions
	Knowledge Management Systems	Creating systems for documenting crisis experiences and making them available as learning resources for future use
	Learning Culture	Fostering an environment where past crises are analyzed, and lessons learned are integrated into future strategies
Communication	Crisis Communication Plans	Establishing protocols for clear and transparent communication with all stakeholders during crises
	Internal Communication Networks	Building robust internal communication systems to ensure the flow of critical information across departments
	Media Management	Managing information dissemination through social media and traditional media to control the crisis narrative.
	Stakeholder Engagement	Building and maintaining relationships with stakeholders to create trust and collaboration during crises
Human Resource Management	Employee Assistance Programs (EAPs)	Offering support services such as mental health counseling, financial advice, stress management training to help employees cope during difficult times
	Employee Training and Development	Ensuring continuous learning opportunities to equip employees with the skills necessary to navigate crises
	Flexible Work Arrangements	Allowing remote work or flexible hours to support employees during crises
	Work-Life Balance Initiatives	Ensuring employees have the flexibility to maintain work-life balance during crises, such as through remote work or flexible hours

Cont. table 1.

Organizational Structures	Agile Frameworks	Applying agile methodologies to allow for rapid iteration and adaptation in response to emerging crises
	Cross-Functional Teams	Creating teams with diverse skills and expertise to quickly and creatively address problems from multiple angles
Resource Management	Diversification of Revenue Streams	Diversifying sources of revenue across different products, services, or geographical areas to reduce risk
	Financial Reserves	Establishing financial buffers, such as emergency funds, to help withstand economic downturns
	Flexible Infrastructure	Designing systems that can be easily reconfigured or repurposed during crises
	Redundant Resources	Maintaining backup systems and resources, such as alternative suppliers, to ensure operational continuity
Planning, Risk Assessment & Management	Early Warning Systems	Implementing monitoring systems to detect early signs of crises, allowing for timely responses
	Risk Identification and Assessment	Conducting comprehensive risk assessments to identify potential vulnerabilities and threats before crises occur
	Scenario Planning/ Contingency Plans	Developing multiple crisis scenarios and planning alternative strategic responses for each to ensure preparedness
Innovation & Technological Integration	Cybersecurity	Strengthening cybersecurity to prevent disruptions caused by cyber-attacks
	Data Analytics	Using real-time data analytics to monitor and respond to crises in an informed manner
	Digital Transformation	Leveraging digital tools and technologies to enhance flexibility and improve response capabilities
	Flexible Business Models	Building adaptability by diversifying products, services, or markets to reduce dependence on a single business model
	Innovation Hubs	Encouraging creative problem-solving through dedicated innovation hubs or task forces designed to find novel solutions during crises
Collaborative Networks	Community Engagement	Building strong ties with local communities to increase organizational support during crises
	Industry Collaboration	Partnering with other organizations within the industry to share resources and knowledge during crises.
	Inter-organizational Cooperation	Building coalitions with competitors or industry groups to create collective resilience
	Public-Private Partnerships	Collaborating with government agencies or non-profits to leverage support and resources for crisis response.
Supply Chain	Inventory Buffers	Maintaining buffer stocks or safety inventories to reduce the impact of supply chain disruptions
	Supplier Diversification	Diversifying suppliers to reduce dependency on a single source and ensure continuity during disruptions
	Supply Chain Risk Monitoring	Implementing tools to monitor and manage risks throughout the whole supply chain

Source: own elaboration on the basis of the cited literature.

As it can be seen, building resilience during a crisis involves various approaches, methods, and forms aimed at enhancing an organization's ability to absorb shocks, adapt to challenges, and recover from disruptions.

3. Methodology

To realize study objectives we utilized a critical analysis of the literature on the subjects of resilience and crisis. This main source of information was supplemented by the selected results of a qualitative research, i.e. a semi-structured personal interview conducted with 20 managers and specialists. The interviews were a part of a larger project, aimed at exploring relations between resilience and inclusiveness in times of crisis, and their results were to assist in preparing a measurement instrument for the main quantitative research planned for that project. Part of the questions (7) included in an interview scenario focused on exploring managers' subjective opinions about the potential (including positive) effects of the crisis on the organizations and the actual impact of the crises resulting from the COVID-19 pandemic and the war in Ukraine on the resilience of the companies they represented.

The interviewees were members of the postgraduate studies in management organized at the University of Economics in Katowice in academic year 2023/2024 who volunteered to participate in the study. The interviews were conducted in May and June 2024. The measurement instrument was an interview scenario, that included a determined list of predominantly open-ended questions, supplemented by additional instructions, and allowing a researcher to ask follow-up questions (Widiger, 2001). Table 2 shows the basic characteristics of the companies represented by the interviewed specialists. As it can be seen, the sample was dominated by the managers of large organizations with extensive years of operation, what should be taken into account when analyzing the respondents' answers.

Table 2.
Sample characteristics

Classification of the companies represented by the respondents		**No.**
Type of industry	service industries	8
	manufacturing and construction industries	7
	knowledge-based industries	5
Size of a company	small (up to 49 employees)	2
	medium (50 to 249 employees)	2
	large (more than 250 employees)	16
Period of operation	up to 15 years	4
	between 15 and 30 years	8
	above 30 years	8
Total		20

Source: own elaboration.

The data obtained from interviews were verified, initially coded, and entered into the database. Then the patterns across responses were analyzed to identify common themes, issues, and categories. The overall discourse analysis of the interview results was conducted within the context of the research questions and aimed at deeper understanding of managers' opinions about relations between the crises and their organizations' resilience. We specifically searched for themes related to: crisis perception and responses, changes in management style and in managers themselves resulting from the crisis conditions, and examples of activities resulting from and leading to the resilient mindset of those managers.

4. Findings

Interview results are described in the following order:

- general opinions about a crisis and its potential positive implications (Question 1),
- solutions/actions implemented during the last crises to support company's resilience and their main goals (Questions 2 and 3),
- benefits for the day-to-day operations of the businesses resulting from implementation of the resilience-building measures (Question 4),
- assessment of the latest crises impact on the companies' competitive advantage, position, and resilience (Questions 5-7).

Question 1 asked whether crises and hardships bring only negative effects to companies or maybe something positive can come out of them, and if so, what are those positive aspects? In response to this question all interviewees but one stated that crises may and actually have positive consequences. It is possible to identify two main views expressed by respondents.

According to the first (n = 11), the crisis provides an opportunity to learn, to draw lessons for the future, and to make better plans for potential next crises. Respondents stated e.g.:

- "[…] *crisis is learning that provides a basis for future improvement*",
- "[…] *crisis allows to identify your most valuable customers, and also check the commitment and performance of your employees*",
- "[…] *a company in difficulty can make adequate future-proofing plans*",
- "[…] *difficulties in a crisis help build resilience to future problems; especially if you can learn your lessons, you can then prepare the company for the future*".

Within this view, several statements emphasized that the crisis allows to detect possible errors and weaknesses (e.g. in the organization performance, its procedures) and therefore to eliminate them before next problems appear. Examples of statements representing this opinion include:

- "[…] *crisis situations show, e.g., that certain procedures are missing and need to be prepared, identify areas for improvement*",
- "[…] *crisis helps to verify existing procedures, strength and stability of the organization*",
- "[…] *yes, crisis offers an opportunity to change ossified procedures, and make necessary, sometimes difficult but developing changes in some processes, in HR*".

The second viewpoint that emerged during interviews (n = 9) presented the crisis as a factor stimulating growth, development, and a positive change, which is in line with the concept adopted in this article. The following opinions reflect this concept:

- "[…] *crises uncover hidden talents and abilities of the company and its employees*",
- "[…] *every crisis reinforces the company's strengths and builds on its history*",
- "[…] *competitive advantage can arise from changes introduced due to a crisis*".

Question 2 asked respondents whether they implemented any solutions, changes or investments during the past crises to support their company's resilience to possible future shocks, and if so, what were those solutions/investments? Six participants responded negatively, and one even stressed that the situation was opposite – several planned investments were withheld due to the crisis. However, as many as fourteen interviewees indicated several areas/forms of changes implemented during the crisis, among which they mentioned: entering new markets and/or introducing new products to the offer (n = 6); modifications in human resource management (n = 6) and overall company organization (n = 4), and finally – investments in new technologies (mostly computers, n = 5). Examples of statements referring to those groups of actions are provided below:

- *"*[…] *we were undertaking activities on many fronts to secure diversification and flexibility of our actions"; "*[…] *we started cooperation with new partners, entered new sectors, and introduced new products into the offer to diversify risk"; "*[…] *we expanded our markets and hired experts to help us",*
- *"*[…] *yes, we have adopted better methods of motivating our staff"; "*[…] *new rules on delegation of tasks/decisions and authority were introduced"; "*[…] *we have refined the operating rules, improved procedures right where the problems have emerged"; "*[…] *we introduced a new monitoring system, implemented security procedures, and expanded structures by introducing new positions: controllers, auditors, analysts",*
- *"*[…] *we improved our computer equipment"; "*[…] *company invested in new computer equipment adapted to the new situation and remote meetings, also carried out training for employees".*

When asked about the priorities in taking the measures increasing resilience (Q3), respondents indicated the most often operational efficiency (business agility, lack of disruptions) (n = 9), followed by the customer retention and maintaining previous service levels and quality (n = 8). The least popular was the goal connected with improving financial performance and profitability of the company, indicated by only three participants.

Question 4 asked participants to state if the resilience-building measures implemented during crises benefit the day-to-day operations of the business. Only two respondents answered negatively and three had no opinion, while the other fifteen indicated examples of the positive consequences of the adopted changes, stressing e.g., "[…] *yes, we are now better prepared for possible future crises*"; "[…] *yes, they provided a sense of security and they show that whatever the situation, the company can cope*".

At the end we asked interviewers to assess whether their organizations managed to develop a competitive advantage as a result of responding to the crisis situation. Eight responded positively, and one stated "[…] *definitely yes, mainly due to improved relationships and teamwork*". In response to Question 6 asking about changes in company's position after the last crises caused by pandemic and war in Ukraine, only one respondent declared that their position was weakened, nine indicated no change, but half of interviewees (n = 10) stated that their company's position was actually strengthened. As a result majority of participants assessed their current organizations' resilience (Q7) as either high (n=6) or even very high (n = 11). Some of them explained these opinions by stating the following: "[…] *we have improved flexibility and the ability to adapt to different situations*"; "[…] *our employee engagement has increased"*; "[…] *our staff's resilience has improved*".

5. Discussion and conclusions

Research indicates that crises often reveal organizational weaknesses, which can, in turn, stimulate innovation aimed at enhancing resilience. For instance, a study by McKinsey & Company (Diedrich et al., 2021) found that approximately half of executives reported that the COVID-19 crisis exposed deficiencies in their companies' strategic resilience. Results of this study are in line with this observation since the interviewed managers also perceive the crisis primarily as the chance to identify but also to eliminate company's weaknesses, like e.g. ineffective or missing procedures. But what is important, many respondents see a crisis as an opportunity to develop through overcoming obstacles and introducing positive changes.

Addressing the second and third research questions, i.e. how to shape resilience and build the resilient mindset, we have established that the resilience is a very complex, multi-faceted category (Chen et al., 2021; Kołodziej, 2023; Żak, 2023). It is neither single capability nor particular resource and not even the most advanced strategy. The interviewed managers perceiving their companies as resilient, mentioned various forms of flexibility, openness to new options, readiness to change but also maintaining relations with customers and motivating and encouraging employees. Hence, resilience is best described as the right combination of the necessary resources (e.g. allowing to invest in new equipment), adequate decisions and behavioral reactions (e.g. about introducing new product to an offer, entering new market, or changing HRM rules), sufficiently strong relations (e.g. with employees, suppliers, customers) but also proper psychological attributes of individuals managing their own as well as their organization's reactions to crisis.

Bugaj & Witek (2022) mention such competences as attentiveness, self-confidence, courage, calmness and ability to control stress as critical for modern managers. At the same time Fiksel (2003, as cited in Bhamra et al., 2011) identifies four critical characteristics of any system that contribute to its resilience, i.e. diversity (reflecting the existence of multiple forms and behaviours); efficiency (ability to perform with modest resource consumption); adaptability (i.e. flexibility to change in response to new pressures); and cohesion (representing existence of unifying relationships and linkages between various system variables and elements). Moreover Nascimento et al. (2021) demonstrate how an isolated mechanism or practice may not ensure ability to withstand adverse conditions by using the concept of sheaf. They suggest that like a stick that does not support a lot of weight, but when coupled with other sticks, ends up with a higher load, the set of adequate mechanisms and practices, organized as a sheaf (bundle of sticks), allows the resilience to grow. The authors also demonstrate that collaboration is essential for building resilience and reducing the impact of possible unavoidable disruptions (Nascimento et al., 2021).

We argue that all the above-mentioned elements combine into the resilient mindset that encompasses the adaptive and proactive attitudes, strategies, and behaviors adopted by organizations, institutions, or individuals within the marketplace to withstand and recover from adverse conditions, disruptions, or shocks. This mindset is characterized by a continuous pursuit of growth opportunities, even in highly turbulent environments, and by cultivating flexibility, adaptability, and innovation within their operations (Coutu, 2002; Duchek, 2020). It is possible that exactly the resilient mindset makes the critical difference between those market entities that flourish as a result of the crisis and those that fail or are able to barely survive the times of hardship.

The resilient mindset then involves both psychological and organizational dimensions. Summarizing the study we may state that in times of crisis it is developed by:

- changes in the structure and processes (changes in decision-making, communication, and operational efficiency, improving agility and flexibility, strengthening relations with other entities),
- learning from mistakes and weaknesses (identification of pre-crisis deficiencies, e.g., inefficient processes; eliminating these weaknesses to prepare for future crises),
- innovation and strategic realignment (diversification of activity and markets, implementing new business models).

6. Study limitations and directions of future research

With the conducted analyses we have contributed to the field by adopting relatively new perspective and reframing crisis as an opportunity for growth rather than solely as a risk. As it was shown, crises can lead to long-term benefits, such as increased agility, innovation, and competitiveness. This, however, is possible only if the organization as well as their managers and employees are capable of learning from the experience and implementing constructive changes.

This study has important limitations. First of all, this was an exploratory and a qualitative research, hence the results cannot be treated as representative. Moreover, the sample was small and the participants represented mostly well established, large companies that had survived many crises and whose experience is therefore considerably distinct from that of smaller and/or new companies that have only recently started their business. The future research in this area should more specifically address the crisis-stimulated resilience of other market entities, including employees, consumers and non-profit institutions. It may also focus on practical solutions leading to creation and maintaining the resilient mindset in organizations and individuals. Since the literature is still lacking empirical studies showing how organizations, particularly SMEs, can achieve resilience, more real world-based research is required.

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MOTIVATION IN THE WORKPLACE – GENDER PERSPECTIVE

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Purpose: The purpose of this paper is to recognize employee motivation considering gender differences. Specific aims include evaluating the levels of motivation and understanding perceptions of both material and non-material motivational factors.
Design/methodology/approach: The empirical research discussed in this article is part of a broader study on work motivation. This study utilized a quantitative approach, employing an online survey questionnaire created with Google Forms as the research tool. The empirical research was conducted in 2023, using purposive sampling to target 120 participants. The questionnaire was disseminated electronically. The theoretical framework was developed using data sourced from the Scopus database, which was analyzed with Scopus AI and VOSviewer software tools. Statistical analysis was conducted using PS Imago Process.
Findings: The empirical research results revealed no statistically significant differences between women and men regarding their level of motivation. However, significant differences were found in terms of material motivational factors between genders. Non-material motivational factors were categorized into organizational and psychological tools. While there were no statistically significant differences between women and men concerning organizational motivational factors, significant differences emerged in the context of psychological motivational factors.
Originality/value: The research findings can serve as a foundation for evaluating motivation systems implemented in organizations during post-pandemic conditions. The empirical studies have underscored differences in the motivation levels of women and men. Future research should prioritize the study of women in the labor market, as understanding their unique needs is crucial for comprehending their motivations and sources of inspiration, which differ from those of men. These research results may be of interest to scholars investigating motivation systems, management students, and organizations.
Keywords: motivation, gender, women.
Category of the paper: Research paper.

Introduction

The highly competitive landscape of modern organizations demands engaged and well-motivated employees. Research shows a link between motivation and factors such as job stability, employee commitment, job satisfaction, improved teamwork efficiency, and increased productivity and performance. As such, understanding employee motivation is vital for the success, growth, and even survival of today's organizations (Amor, 2023; Gagné et al., 2014; Imran et al., 2017; Mahmoud, Reisel, 2014; Rusu, Avasilcai, 2013; Syahchari, 2019; Tudorache, 2013).

Motivation is a crucial element in people's professional lives, often described as the process of psychological regulation that stimulates and directs behaviors consciously or unconsciously (Chodkowski, 2019). Pritchard and Ashwood (2008) defined motivation as the "process used to allocate energy to maximise the satisfaction of needs".

In the literature exploring motivation, various theories attempt to explain human behavior in organizations. Therefore, the topic remains current and continually seeks sources of human motivation (Gajdek, 2015). Two approaches to motivation theory can be distinguished: needs theories (content theories) and process theories. Needs theories seek to identify what motivates people to work, while process theories explore methods of motivating people at work (Kilian, 2020).

In numerous scientific studies, motivation is categorized as either intrinsic or extrinsic. Intrinsic motivation originates from within an individual, meaning that a person engages in an activity by choice, interest, or pleasure, often with considerable effort and engagement. Conversely, extrinsic motivation involves individuals taking actions to achieve a reward or benefit. This type of motivation also includes conscious influence exerted on employees by supervisors through penalties, rewards, salaries, and various non-financial methods (Shevchenko et al., 2023; Żukowska, 2017).

Various tools, also known as motivators, factors or instruments, are used. These instruments are categorized based on how they influence employees and include: coercive tools (e.g., prohibitions, regulations, directives), persuasion (training and courses, consultations), and incentives (economic and non-economic). Among the material (economic) factors, one can distinguish: wage, primarily including salaries, and non-wage measures, aimed at shaping and stimulating human motivation by offering employees various additional benefits, such as social benefits, training funding, or insurance. Non-material (non-economic) factors, on the other hand, consist of various additional benefits (Kaczyńska et al., 2015; Knap-Stefaniuk et al., 2018; Strojna, 2015).

Research indicates that there are gender differences in motivation, with women often displaying higher levels of autonomous and intrinsic motivation compared to men. Additionally, females may experience higher levels of anxiety related to achievement motivation. Women and men may also differ in their perceptions of motivational tools. However, it's important to note that the specific types of motivation and the extent of gender differences can vary across different contexts (Butler, 2014; Iwaniec, 2019; Samir, Krishnasamy, 2019; Sharma et al., 2020).

Exploring gender disparities in motivation is vital for contemporary organizations. Understanding women's motivation enables customized interventions that empower them, cultivating inclusive work environments. Recognizing women's distinct needs helps in grasping their drivers and sources of inspiration, which may vary from those of men. This comprehension guides workplace policies that bolster retention, career progression, and job satisfaction, consequently impacting the outcomes achieved by organizations (Cabrera, Quesada, 2020; Pino-Juste et al., 2021; Rezamahalleh et al., 2020).

Despite extensive literature on motivation, further research appears necessary due to changes in the business environment. Researchers examining work motivation highlight changes in this area due to the COVID-19 pandemic (Chala et al., 2022; Goh, Baum, 2021). Findings suggest that pandemic-related restrictions have reshaped the motivational profiles, emphasizing values like self-awareness, health maintenance, work-life balance, and personal growth.

The main objective of the research is to recognize employee motivation considering gender differences. Specific objectives include assessing levels of motivation and understanding perceptions of material and non-material motivational factors. The research results can provide a foundation for contemplating motivation systems applied in organizations under post-pandemic conditions.

Theoretical background

The empirical studies discussed in this paper represent one aspect of research into work motivation that concerns generational distinctions. The theoretical background is based on the Scopus database and consists of two stages: the analysis of publications in the areas of motivation and generation and, in the second stage, the analysis of publications in the areas of motivation and gender. In the first stage, publications were searched for using the keywords "motivation" and "generation", and the results were limited to English-language journal articles, with a total of 6321 articles being obtained. To present the current topics addressed within management sciences in the field of motivation in the context of generation, the database was limited to the scientific areas of business, management, and accounting. A database of 210 publications from the years 2010 to 2024 was obtained.

The co-occurrence analysis for all keywords was performed using VOSviewer software. It was assumed that the minimum number of occurrences for a keyword should be 4. Figure 1 illustrates the connections between the topics of motivation, generation, and other keywords. Four primary research areas (thematic clusters) were identified and are highlighted in the figure with different colors: Innovation and Knowledge (red), Current Problems (green), Generation (blue), and Motivation (yellow). One research area focuses on motivation by generational affiliation (X, Y, Z). These studies also take into account the issue related to gender (blue cluster). The number of occurrences of each keyword and the strength of its connections are presented in Table 1.

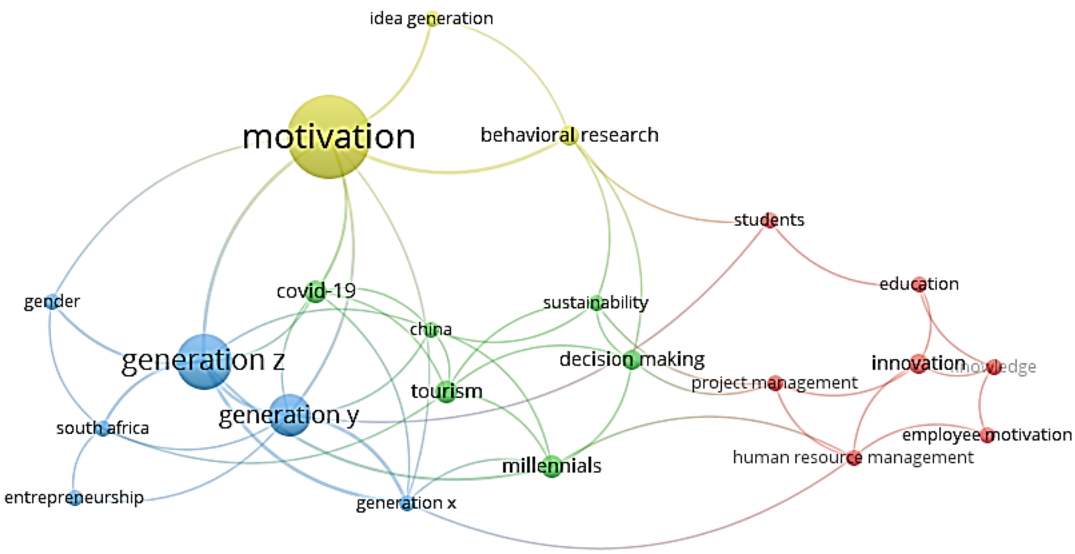

Figure 1. The research areas related to motivation in the context of generations (VOSviewer).
Source: Czerwińska-Lubszczyk, Jankowiak, 2024.

Table 1.
The number of occurrences of each keyword and the strength of its associations for the selected thematic cluster (blue)

Key word	Occurrence	Total link strength
Generation Z	18	17
Generation Y	13	13
Generation X	4	10
South Africa	4	6
Gender	4	4
Entrepreneurship	4	2

The authors address current socio-economic issues such as: robotized workplaces (Turja et al., 2022), agile companies (Revutska, Maršíková, 2021), women in STEM (Bhore, Tapas, 2023), employee-driven innovation (González-González, García-Almeida, 2021), and pandemic (Chala et al., 2022; Goh, Baum, 2021; Mahmoud et al., 2021). The research is carried out using quantitative methods (Turja et al., 2022) or qualitative methodologies (Lechler, Huemann, 2024).

Motivation at work

The authors adopt different perspectives on motivation and concentrate their research on various factors influencing motivation at work. Peñalba-Aguirrezabalaga et al. (2021) classify motivation into intrinsic and extrinsic types. Their findings highlight the importance of intrinsic motivation, where individuals engage in activities because they find them inherently interesting and derive spontaneous satisfaction from the activity itself. In contrast, extrinsic motivation involves engaging in activities for instrumental reasons (Gagné et al., 2010).

On the other hand, González-González and García-Almeida (2021) measured motivation by intrinsic motivation, extrinsic motivation (direct rewards), and the perception of the presence of motivating suggestion systems (extrinsic motivation; heeded suggestions). Turja et al. (2022) categorized workplace needs into material basic needs and psychological needs (such as feelings of competence, autonomy, and relatedness). Easton and Steyn (2022) focused on work values. Extrinsic work values include aspects such as salary and compensation growth, career advancement opportunities, flexible work practices, engaging and challenging tasks, job role autonomy, and fewer constraints. Intrinsic work values encompass personal development, recognition, work-life balance, alignment with employer values and ethics, and the opportunity to contribute through innovative ideas.

The researchers highlight the necessity of considering the characteristics of the motivated individuals, such as generational affiliation or gender (Chala et al., 2022; Boyle, 2022; Lechler, Huemann, 2024). Mahmoud et al. (2021) found that Generation Z shows higher sensitivity to amotivation compared to Generation X and Generation Y. Their study revealed that Generation Z finds extrinsic regulation-material particularly significant for overall work motivation. In contrast, Generation X values extrinsic regulation-social, while Generation Y values introjected regulation. Both Generation X and Generation Y employees value identified regulation as a source of overall work motivation, unlike Generation Z. Additionally, intrinsic motivation plays a more substantial role in motivating Generation Z employees compared to Generation X and Generation Y. Boyle (2022) observed in their research that millennials demonstrated increased adaptability, self-drive, and intrinsic motivation following their transition into the workforce, distinguishing them from previous generations.

Motivation and gender

Gender plays a significant role in determining motivational factors. While work motivation is a universal concern, gender differences can influence how individuals perceive and respond to various organizational strategies aimed at improving these outcomes (Kamil et al., 2024). Doerwald et al. (2021) focused on generativity at work, which involves both the motivation and behavior to support and guide younger generations and benefit future ones. Their findings indicate a positive association between the generativity motive and personal factors such as gender. Lašáková et al. (2023) examined motivating and demotivating factors for both genders.

Their results show that Gen Z women prioritize social aspects of workplace relationships, intrinsic factors related to ideal job scenarios, minimal routine, job success, and the need for recognition. In contrast, Gen Z men prioritize making a meaningful impact at work through altruism, extrinsic benefits, and aspects of a satisfying personal life free from work-related stress. Bhore and Tapas (2023) specifically studied Generation Z women, identifying factors that help organizations create policies and work environments to attract and support them in data science roles. Technical education, job opportunities, compensation, and supportive environments significantly and positively influence career decisions among Gen Z women in this field.

In the final stage of literature review, Scopus AI tool was utilized to search for publications on the topic of this study: "Motivation in the workplace – gender perspective". The generated results (publications) were subjected to analysis.

The gathered research indicates that gender plays a multifaceted role in workplace motivation, impacting variables such as job satisfaction, leadership styles, and psychological well-being (Memon, Jena, 2017; Salleh et al., 2018; Štefko et al., 2017). Lorincová et al. (2019) noted from their research conducted in Slovak enterprises that there are statistically significant differences in motivation perception based on job category and gender, particularly among blue-collar workers. Kamil et al. (2024) demonstrated that female employees generally show slightly lower levels of motivation compared to males, although this difference is not statistically significant. However, it is worth noting that some studies have found no statistically significant differences in motivation levels between genders. Ufuophu-Biri and Iwu (2014) reported no significant correlation between gender and job motivation or job performance, respectively.

Based on the literature analysis, the following hypotheses were formulated:

H1: There are differences between women and men in their levels of motivation.

H2: Women and men differ in their perceptions of material motivational factors.

H3: Women and men differ in their perceptions of non-material motivational factors.

Research methodology and sample structure

The theoretical framework relies on the Scopus database and involves two stages: analyzing publications related to motivation and generation, and subsequently analyzing publications focused on motivation and gender. The literature review for this publication was conducted in the first half of 2024.

The empirical studies discussed in this paper is a part of empirical research on work motivation that specifically examines generational differences. The study's scope included analyzing work motivation among individuals from generations X, Y, and Z. It focused on individuals in the workforce belonging to these generations, defined by age boundaries as outlined by Sidor-Rządkowska (2018): Generation X (born between 1965 and 1979), Generation Y (born between 1980 and 1994), and Generation Z (born from 1995 onwards). The research targeted individuals currently employed in public institutions, enterprises, or other organizations, as well as those engaged in entrepreneurial activities. It also considered individuals who were previously employed but are currently not working due to reasons such as illness, vacation, maternity leave, flexible work arrangements, training participation, or other temporary absences not exceeding three months (according to GUS criteria). The empirical research was conducted in 2023.

The study utilized a quantitative approach, employing an online survey questionnaire created with Google Forms as the research tool. Purposive sampling was adopted, targeting 120 participants evenly distributed across three generational cohorts, with 40 individuals from each. The questionnaire was disseminated electronically.

Table 2.
Sample structure

	Female (N)	Male (N)	Female (%)	Male (%)
Employment contract	59	39	78.67%	86.67%
Civil law contract	15	5	20.00%	11.11%
Other	1	1	1.33%	2.22%
sum	75	45	100.00%	100.00%
Generation Z	33	7	44.00%	15.56%
Generation Y	22	18	29.33%	40.00%
Generation X	20	20	26.67%	44.44%
sum	75	45	100.00%	100.00%

The sample comprises 120 individuals from three generations (Table 2), including 75 women (62.5%) and 45 men (37.5%). The majority of the sample consisted of individuals employed under an employment contract (F: 78.67%, M: 86.67%).

The theoretical framework was formulated based on data extracted from the Scopus database, and analyzed using Scopus AI and VOSviewer software tools. Statistical analysis was performed using PS Imago Process.

Results

To assess the level of motivation, the following statement was used: Please rate the extent to which you feel motivated to work. Respondents had the option to answer on a five-point scale: 1 – I am not motivated, 2 – I feel low motivation to work, 3 – It's hard to say, 4 – I feel that I am motivated, 5 – I am very strongly motivated to work. The statistical data is presented in Table 3. The Mann-Whitney U test was used to compare the levels of motivation between females and males and yielded the following values: Z = -1.748 and p = 0.081. Based on the adopted alpha level of 0.05, it can be concluded that there are no statistically significant differences between women and men in terms of their level of motivation.

Table 3.
Level of motivation by male and female

	Total	**Female**	**Male**
N	120	75	45
Mean	3.59	3.73	3.36
M	4.00	4.00	4.00
D	4.00	4.00	4.00
SD	1.18	1.15	1.21
Min	1.00	1.00	1.00
Max	5.00	5.00	5.00
Q1	3.00	3.00	2.00
Q3	4.00	5.00	4.00

Motivational factors are categorized into material and non-material types. which were categorized into organizational and psychological (Kaczyńska et al., 2015; Turja et al., 2022). The first group of statements were formulated: Please assess the following material motivating factors: Salary level (WYNA), Financial bonus (PREM), Performance-based pay (WYNI), Training and professional development funding (SZKO), Work phone. laptop (TELE), Company car (SAMO), Company meals (OBIA), Organizing company events (IMPR), Legal and financial assistance (DORA), Discounts on company products (ZNIŻ), Team-building trips (WYCI), Parking spaces (PARK), Benefits - e.g., multisport card. health insurance. subsidies for vacations. subsidies for education costs e.g., foreign languages, etc. (BENE). The response options included: 1 – Does not affect my motivation, 2 – Has a low impact on my motivation, 3 – I'm not sure if it affects my motivation, 4 – Has an impact on my motivation, 5 – Has a very high impact on my motivation (Czerwińska-Lubszczyk, Jankowiak, 2024). The statistical data is presented in Table 4.

Table 4.
Material motivational factors by gender (female and male)

Total	**WYNA**	**PREM**	**WYNI**	**SZKO**	**TELE**	**SAMO**	**OBIA**	**IMPR**	**DORA**	**ZNIŻ**	**WYCI**	**PARK**	**BENE**
N	120	120	120	120	120	120	120	120	120	120	120	120	120
Mean	4.15	4.45	3.67	3.45	3.13	3.05	2.76	2.93	3.21	2.81	2.73	3.00	3.63
M	5.00	5.00	4.00	4.00	3.50	3.00	3.00	3.00	4.00	3.00	3.00	3.00	4.00
D	5.00	5.00	5.00	5.00	4.00	4.00	4.00	4.00	4.00	1.00	4.00	4.00	5.00
SD	1.16	0.80	1.49	1.53	1.28	1.36	1.29	1.38	1.48	1.46	1.35	1.30	1.59
Min	1.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Max	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Q1	4.00	4.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.00	1.00	2.00	2.00
Q3	5.00	5.00	5.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	5.00
Female	**WYNA**	**PREM**	**WYNI**	**SZKO**	**TELE**	**SAMO**	**OBIA**	**IMPR**	**DORA**	**ZNIŻ**	**WYCI**	**PARK**	**BENE**
N	75	75	75	75	75	75	75	75	75	75	75	75	75
Mean	4.13	4.47	4.01	3.60	3.00	2.67	2.99	3.11	3.32	2.99	2.96	3.05	3.93
M	5.00	5.00	5.00	4.00	3.00	3.00	3.00	3.00	4.00	3.00	3.00	3.00	5.00
D	5.00	5.00	5.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	5.00
SD	1.18	0.74	1.38	1.50	1.21	1.24	1.28	1.33	1.48	1.44	1.39	1.25	1.50
Min	1.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Max	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00

Cont. table 4.

Q1	**4.00**	**4.00**	**3.00**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**3.00**
Q3	5.00	5.00	5.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	5.00
Male	**WYNA**	**PREM**	**WYNI**	**SZKO**	**TELE**	**SAMO**	**OBIA**	**IMPR**	**DORA**	**ZNIŻ**	**WYCI**	**PARK**	**BENE**
N	45	45	45	45	45	45	45	45	45	45	45	45	45
Mean	4.18	4.42	3.09	3.20	3.36	3.69	2.38	2.64	3.02	2.51	2.33	2.91	3.13
M	5.00	5.00	3.00	4.00	4.00	4.00	2.00	2.00	3.00	2.00	2.00	3.00	3.00
D	5.00	5.00	2.00	5.00	4.00	4.00	2.00	4.00	4.00	1.00	2.00	4.00	5.00
SD	1.15	0.89	1.50	1.56	1.37	1.31	1.23	1.42	1.47	1.46	1.21	1.38	1.63
Min	1.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Max	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Q1	4.00	4.00	2.00	2.00	2.00	3.00	1.00	1.00	2.00	1.00	1.00	2.00	1.00
Q3	5.00	5.00	5.00	5.00	4.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	5.00

The Mann-Whitney U test was used to compare the differences between two independent groups: females and males (Tab. 5). Based on the adopted alpha level of 0.05, it can be concluded that there are statistically significant differences between women and men in terms of: Performance-based pay (WYNI), Company car (SAMO), Company meals (OBIA), Team-building trips (WYCI), and Benefits (BENE). It can be concluded that women tended to rate the importance of material motivational factors higher than men.

Table 5.

The Mann-Whitney U test for material motivational factors (female and male)

	WYNA	PREM	WYNI	SZKO	TELE	SAMO	OBIA	IMPR	DORA	ZNIŻ	WYCI	PARK	BENE
Z	-0.12	-0.14	-3.34	-1.22	-1.70	-4.07	-2.42	-1.73	-1.10	-1.65	-2.33	-0.52	-2.84
p	0.90	0.89	0.00	0.22	0.09	0.00	0.02	0.08	0.27	0.10	0.02	0.60	0.00

The next phase focused on examining non-material factors. The survey asked respondents to evaluate non-material motivational factors, which were divided into organizational and psychological categories. The organizational factors included: flexible working hours (ELAS); work-life balance (WLB); participation in developmental projects (PROJ); possibility of remote work (ZDAL); conveniently scheduled leave (URLO); and access to modern technologies (TECH). The psychological aspects included: self-fulfillment (SAMO); recognition (POCH); job stability (STAB); good relationships with colleagues (RELA); positive interpersonal relationships with supervisors (KONT); and trust within the company (ZAUF). The response options included: 1 – Does not affect my motivation; 2 – Has a low impact on my motivation; 3 – I'm not sure if it affects my motivation; 4 – Has an impact on my motivation; and 5 – Has a very high impact on my motivation (Czerwińska-Lubszczyk, Jankowiak, 2024). The statistical data is presented in Table 6.

Table 6.
Non-material motivational factors (organizational and psychological) by gender (female and male)

Total	ELAS	WLB	PROJ	ZDAL	URLO	TECH	SAMO	POCH	STAB	RELA	KONT	ZAUF
N	120	120	120	120	120	120	120	120	120	120	120	120
Mean	3.28	3.89	3.73	3.30	3.39	3.28	3.77	3.30	4.23	3.60	3.43	3.87
M	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	5.00	4.00	4.00	4.00
D	5.00	5.00	5.00	4.00	4.00	4.00	5.00	4.00	5.00	4.00	4.00	4.00
SD	1.68	1.19	1.47	1.52	1.48	1.46	1.28	1.29	1.06	1.33	1.41	1.24
Min	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Max	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Q1	1.25	3.00	2.00	2.00	2.00	2.00	3.00	2.00	4.00	2.00	2.00	4.00
Q3	5.00	5.00	5.00	5.00	5.00	4.00	5.00	4.00	5.00	5.00	5.00	5.00
Female	**ELAS**	**WLB**	**PROJ**	**ZDAL**	**URLO**	**TECH**	**SAMO**	**POCH**	**STAB**	**RELA**	**KONT**	**ZAUF**
N	75	75	75	75	75	75	75	75	75	75	75	75
Mean	3.43	3.79	3.79	3.53	3.52	3.41	3.85	3.64	4.24	3.81	3.49	4.09
M	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	5.00	4.00	4.00	4.00
D	5.00	5.00	5.00	4.00	5.00	4.00	5.00	4.00	5.00	5.00	5.00	5.00
SD	1.69	1.26	1.45	1.44	1.47	1.44	1.28	1.24	1.02	1.31	1.41	1.16
Min	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00	1.00	1.00	1.00
Max	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Q1	2.00	3.00	2.00	2.00	2.00	2.00	3.00	3.00	4.00	3.00	2.00	4.00
Q3	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Male	**ELAS**	**WLB**	**PROJ**	**ZDAL**	**URLO**	**TECH**	**SAMO**	**POCH**	**STAB**	**RELA**	**KONT**	**ZAUF**
N	45	45	45	45	45	45	45	45	45	45	45	45
Mean	3.04	4.07	3.62	2.91	3.18	3.04	3.62	2.73	4.20	3.24	3.33	3.49
M	3.00	4.00	4.00	3.00	4.00	3.00	4.00	2.00	5.00	4.00	4.00	4.00
D	5.00	5.00	5.00	1.00	4.00	4.00	4.00	2.00	5.00	4.00	4.00	4.00
SD	1.66	1.05	1.50	1.59	1.48	1.48	1.27	1.19	1.12	1.30	1.41	1.27
Min	1.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Max	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Q1	1.00	3.50	2.00	1.00	2.00	1.50	3.00	2.00	3.50	2.00	2.00	2.00
Q3	5.00	5.00	5.00	4.00	4.00	4.00	5.00	4.00	5.00	4.00	4.50	4.00

Table 7.
The Mann-Whitney U test for non-material motivational factors (organizational and psychological) by gender (female and male)

	ELAS	WLB	PROJ	ZDAL	URLO	TECH	SAMO	POCH	STAB	RELA	KONT	ZAUF	ELAS
Z	-1.35	-1.05	-0.66	-1.94	-1.29	-1.42	-1.27	-3.76	-0.05	-2.47	-0.68	-2.87	-0.05
p	0.18	0.29	0.51	0.05	0.20	0.16	0.21	0.00	0.96	0.01	0.49	0.00	0.96

The Mann-Whitney U test was used to compare the differences between two independent groups: females and males (Tab. 7). Based on the adopted alpha level of 0.05. it can be concluded that there are non-statistically significant differences between women and men in the context of organizational motivational factors. There are statistically significant differences between women and men in the context of psychological motivational factors in terms of: recognition (POCH), good relationships with colleagues (RELA) and trust within the company (ZAUF). Additionally, it can be observed that, on average, women rated the importance of both organizational and psychological motivators higher than men.

Discussion and Conclusion

The fierce competition faced by today's organizations necessitates a workforce that is highly engaged and motivated. Research consistently demonstrates a positive correlation between motivation and factors like employee commitment, work satisfaction, enhanced teamwork effectiveness, and boosted productivity and performance (Amor, 2023; Gagné et al., 2014; Imran et al., 2017; Mahmoud, Reisel, 2014; Rusu, Avasilcai, 2013; Syahchari, 2019; Tudorache, 2013). Consequently, understanding employee motivation is paramount for an organization's success, growth, and even its continued existence.

Despite extensive literature on motivation, further research appears necessary due to changes in the business environment. Particularly the impact of the COVID-19 pandemic has significantly reshaped motivational profiles.

This research aims to understand employee motivation with a specific focus on gender differences. Specific objectives include assessing levels of motivation and understanding perceptions of material and non-material motivational factors.

H1: There are differences between women and men in their levels of motivation

The empirical research results indicated that there are no statistically significant differences between women and men in terms of their level of motivation. Therefore, hypothesis H1 was negatively verified. Studies by Kamil et al. (2024) demonstrated that female employees generally show slightly lower levels of motivation compared to males. However, as indicated in the publication, this difference is not statistically significant. Additionally, the study was conducted among Malaysian public sector personnel, which could have influenced the results. The specification of the workplace can affect motivation, as demonstrated by Lechler R.C. and Huemann M. (2024).

H2: Women and men differ in their perceptions of material motivational factors

It can be concluded that there are statistically significant differences between women and men in terms of material motivational tools: Performance-based pay (WYNI), Company car (SAMO), Company meals (OBIA), Team-building trips (WYCI), and Benefits (BENE). Women tended to rate the importance of material motivational factors higher than men. The hypothesis was supported by the research findings.

H3: Women and men differ in their perceptions of non-material motivational factors

Non-material motivational tools were categorized into organizational and psychological factors. There are no statistically significant differences between women and men in the context of organizational motivational factors. However, there are statistically significant differences between women and men in the context of psychological motivational factors, specifically in terms of recognition (POCH), good relationships with colleagues (RELA), and trust within the company (ZAUF). Additionally, it can be observed that, on average, women rated the importance of both organizational and psychological motivators higher than men. The results of the empirical research are consistent with previously conducted research by Doerwald F., Zacher H., Van Yperen N.W., Scheibe S. (2021), and Lašáková et al. (2023), who pointed out statistically significant differences in the motivation of women and men.

The research findings can serve as a background for considering motivation systems implemented in organizations in post-pandemic conditions. The study showed that non-material factors have a relatively high impact on employee motivation, with a broad range of significant factors. Conversely, the significance of material factors varied among employees. Salary level and financial bonus were highly important to employees, whereas company meals, discounts on company products, and team-building trips were rated lower by the respondents.

The empirical studies indicated differences in the motivation of women and men. Future research should prioritize the study of women in the labour market. Understanding the unique needs of women is crucial for comprehending their motivations and sources of inspiration, which differ from those of men.

The primary limitations of this study are related to the size of the sample and the specificity of the workplace context. The empirical research presented here constitutes one phase in a broader exploration of work motivation across different generations. These findings lay the groundwork for further investigation, particularly with a larger sample size.

Furthermore, the current study does not specify the industries or occupations represented in the sample. Subsequent studies should focus on employees within specific industries, as the particular characteristics of workplaces significantly impact employee motivation. It is essential to remember that the implementation or modification of a motivation system in a specific organization should take its unique characteristics into account. This point was emphasized by Lechler R.C. and Huemann M. (2024), who demonstrated that motivators have varying levels of importance in different project and organizational contexts. The motivation system should consider factors, such as the gender and generational affiliation of employees (Czerwińska-Lubszczyk, Jankowiak, 2024). Therefore, it is recommended to conduct research directly within the organization that is preparing, updating, or improving its motivation system to ensure that the motivation system is "tailored" to the specific needs of the organization.

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APPLICATION OF QUALITY FUNCTION DEPLOYMENT IN SUSTAINABLE PRODUCT IMPROVEMENT: A CASE STUDY OF MOBILE PHONES

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Purpose: This study integrates sustainability into smartphone product improvement using the Quality Function Deployment (QFD) method. The goal is to identify customer needs and translate them into technical specifications that align with customer expectations and environmental sustainability.

Design/Methodology/Approach: A survey was conducted with 31 participants to gather feedback on key smartphone features, including battery life, network performance, and energy efficiency. The QFD process, specifically the House of Quality (HoQ) matrix, was used to systematically prioritize these customer requirements alongside technical aspects like energy-saving capabilities, material reduction, and ease of maintenance.

Findings: The analysis revealed that Battery Life, Network Performance, and Touch Screen Sensitivity were the most valued customer requirements, while Energy Saving, Easy Maintenance, and Material Reduction emerged as critical technical attributes for sustainable smartphone design.

Originality/Value: This research offers a novel application of QFD in sustainable smartphone design, providing a framework for manufacturers to enhance customer satisfaction while addressing environmental concerns.

Keywords: Sustainability, Quality Function Deployment (QFD), Smartphone Design, Customer Requirements, Environmental Responsibility.

Category of the paper: Research Paper, Case Study.

1. Introduction

The integration of sustainability into product design, especially in industries with rapid technological advancements like electronics, has become a crucial aspect of contemporary engineering practices. In the smartphone sector, balancing consumer demands with environmental responsibility is challenging due to the high resource usage, carbon emissions, and waste associated with production and disposal processes. Smartphones contribute substantially to environmental issues, with studies emphasizing the necessity for sustainable practices across their lifecycle—from energy consumption and resource extraction to the generation of e-waste (Towler, 2024; Matinmikko-Blue, Arslan, 2023). This context underscores the importance of incorporating sustainable design principles into product development frameworks to align with global sustainability goals like the UN Sustainable Development Goals (SDGs).

Quality Function Deployment (QFD) has emerged as a versatile tool for integrating customer requirements into the design of sustainable products, bridging the gap between technical solutions and customer needs. QFD's application in various industries demonstrates its adaptability; for instance, it has been employed in sustainable nursing bed design (Geng et al., 2024), sustainable mobile applications (Alloghani, 2023), and even aviation seat optimization (Çetin, Üçler, 2023). Through techniques like Life Cycle Assessment (LCA) and integration with methodologies such as Six Sigma, QFD enables sustainable product design that minimizes environmental impacts while enhancing customer satisfaction (Kar, Rai, 2024). The use of QFD in sustainable smartphone design, as highlighted in recent research, offers a structured way to prioritize environmental considerations like energy efficiency, recyclability, and material reduction, thereby addressing both functional and sustainability aspects (Vilochani et al., 2024; Camañes et al., 2024).

This study applies QFD within the context of smartphone design, aiming to translate customer requirements into technical specifications that prioritize sustainability. By utilizing the House of Quality (HoQ) matrix, this research provides a framework for manufacturers to systematically integrate environmental and consumer-oriented design elements, supporting the development of smartphones that align with both market demand and ecological standards.

2. Literature Review

Quality Function Deployment (QFD) has been extensively applied in sustainable product development across various industries, demonstrating its effectiveness in addressing customer requirements and integrating sustainability into product design. The application of QFD in sustainable design is evident in the nursing bed product-service system (PSS), where a scenario-driven dual-layer requirement network and a modified QFD model are used to mine latent requirement attributes (RAs) and prioritize engineering characteristics (ECs) to maximize customer satisfaction while considering cost constraints (Geng et al., 2024). In the remanufacturing industry, an entropy-based fuzzy QFD model has been proposed to transform customer requirements into technical characteristics, emphasizing the importance of restorability and reliability in remanufactured products (Shi et al., 2024). The integration of QFD with eco-design methodologies, such as Life Cycle Assessment (LCA), allows for the optimization of environmental impacts during the design phase, as seen in the development of software tools for sustainable product design (Camañes et al., 2024). Furthermore, the ICT sector has explored sustainable software design through systematic literature reviews, identifying guidelines and techniques for reducing energy consumption and carbon footprint, which can be enhanced by QFD applications (Danushi et al., 2024). In the context of Industry 4.0, a hybrid neutrosophic MCDM approach combined with Six Sigma evaluation and QFD has been introduced to facilitate sustainable product design, providing a computationally inexpensive method for evaluating design alternatives based on ECs (Kar, Rai, 2024). The integration of value engineering with QFD and Design for Assembly (DFA) techniques has been shown to deliver necessary functionalities at the lowest life cycle cost, enhancing client satisfaction and reducing development times without compromising quality (Sistem et al., 2024). The concept of Design for Sustainability (DfS) in product engineering highlights the importance of integrating sustainability principles into product design, where QFD can play a crucial role in addressing environmental, social, and economic impacts (Reddy et al., 2023). The consolidation of management practices for Sustainable Product Development (SPD) further emphasizes the need for systematic incorporation of sustainability considerations, where QFD can aid in navigating the complexities of SPD and selecting relevant practices (Vilochani et al., 2024). The role of QFD in sustainable design is also supported by the increasing focus on product sustainability, time-to-market, and profit, where innovations in product design and development are crucial for addressing sustainable development concerns (Relich, 2023). Finally, the Sustainable Design Evaluation method, which incorporates QFD principles, enables product developers to assess the impact of their decisions across ecological, economic, and social criteria, providing a holistic sustainability assessment that is easy to interpret and apply (Reichard, Martin, 2023). Overall, the literature demonstrates that QFD is a versatile tool in sustainable product development, effectively bridging customer requirements with technical solutions while integrating sustainability across various industries.

Quality Function Deployment (QFD) is a powerful tool for integrating customer requirements into sustainable design practices, offering numerous benefits as highlighted by various studies. QFD facilitates the transformation of customer needs into engineering characteristics, ensuring that products are designed with a customer-centric approach. This is particularly beneficial in sustainable product design (SPD), where balancing customer satisfaction with environmental considerations is crucial. For instance, the integration of QFD with Six Sigma and multi-criteria decision-making (MCDM) techniques in Industry 4.0 contexts has been shown to enhance SPD by providing a structured, effective, and computationally inexpensive method for evaluating design alternatives, thus maintaining a competitive market position while enhancing customer satisfaction (Kar, Rai, 2024). Similarly, the use of QFD in the design of nursing beds demonstrates its ability to capture latent requirements and prioritize engineering characteristics by considering psychological preferences, ultimately maximizing customer satisfaction under cost constraints (Geng et al., 2024). In the context of sustainable manufacturing, QFD has been used to analyze customer participation, revealing that cost implications and government regulations are significant factors influencing sustainable practices (Song et al., 2024). Moreover, the integration of QFD with value engineering and design for assembly (DFA) techniques has been shown to lower expenses, shorten development times, and reduce the need for rework, all while maintaining product quality and performance (Sistem et al., 2024). The application of QFD in the redesign of toothpaste tubes using Green QFD II methodology highlights its role in addressing both usability and sustainability, demonstrating that sustainable products can be developed without compromising functionality (Angtuaco et al., 2023). Furthermore, the QFD-CE method incorporates sustainable development and circular economy principles, setting design goals based on both customer expectations and environmental impact, as demonstrated in the photovoltaic panel industry (Pacana, 2023). In the aviation industry, QFD combined with the analytic hierarchy process (AHP) has been used to optimize aircraft seat design by consolidating product quality characteristics and isolating dependable design variables, emphasizing safety, weight, and durability (Çetin, Üçler, 2023). The use of QFD in the design of an aquatic autonomous observatory for water quality monitoring illustrates its effectiveness in systematically constructing products that fulfill user needs while considering environmental conditions (Shukla, Bhattacharya, 2023). Additionally, the integration of text mining with spherical fuzzy QFD for smartwatches showcases how QFD can leverage online reviews to extract customer requirements and rank technical requirements, thus enhancing product design in a competitive environment (Ayber et al., 2023). Lastly, the use of QFD in the development of Sativa mouthwash demonstrates its ability to prioritize technical interests such as raw material management and halal labeling, which are crucial for green innovation and customer satisfaction (Zafriana, Setiawatie, 2023). Overall, these studies collectively underscore the value of QFD in integrating customer requirements into sustainable design practices, ensuring that products not only meet customer expectations but also contribute to environmental sustainability.

Sustainability in mobile phone production and design is a multifaceted challenge that encompasses various aspects, from energy efficiency to ethical considerations. The global push towards mitigating climate change, as highlighted by the Paris Agreement, necessitates a shift towards carbon neutrality, which impacts the energy and resource use in mobile phone production (Towler, 2024). The integration of sustainability in mobile app development is crucial, as mobile platforms are increasingly complex, with challenges in requirement engineering due to limitations in device capabilities such as processors and batteries (Tanveer et al., 2023). The development of green mobile apps, guided by frameworks like PRISMA, emphasizes the role of digitalization in promoting environmentally conscious behaviors, although developers face challenges in balancing innovation with environmental obligations

(Alloghani, 2023). The transition to 6G mobile communications is also pivotal, as it offers opportunities to align with the UN Sustainable Development Goals (SDGs) by addressing the environmental footprint and energy consumption of communication networks (Matinmikko-Blue, Arslan, 2023) ("Design for sustainability - an imperative for future mobile networks", 2023). The Internet of Production (IoP) can be transformed into an Internet of Sustainable Production (IoSP), optimizing manufacturing processes to be more sustainable, which is crucial for mobile phone production (Bernhard et al., 2023). Additionally, the design of smartphone apps that evaluate product use sustainability, such as those collecting data on battery usage and emissions, can influence sustainable product use and inform future designs (Russell et al., 2024). The Exspiro app exemplifies how mobile applications can contribute to sustainability by reducing food waste, showcasing the potential for apps to address broader sustainability challenges (Pajpach et al., 2023). The pressure to improve energy efficiency in communication networks is compounded by the demand for faster data rates and higher capacities, necessitating a focus on reducing the environmental impact and ensuring inclusivity and fairness in technology use (Remedios et al., 2023). Educational initiatives, such as virtual project-based learning courses, are also essential in equipping future engineers with the knowledge to tackle sustainability challenges in mobile phone design and production, emphasizing the importance of green methodologies (Virtual Studies…, 2023). Overall, the studies underscore the need for a holistic approach to sustainability in mobile phone production and design, integrating technological advancements with environmental and ethical considerations to create a sustainable future.

3. Methodology

The study aims to integrate sustainability considerations into the smartphone product improvement process through a structured approach. The methodology involves customer input collection, the application of the House of Quality (HoQ) framework, and the integration of sustainability metrics into product design. The research procedure was conducted according to the stages presented in Figure 1.

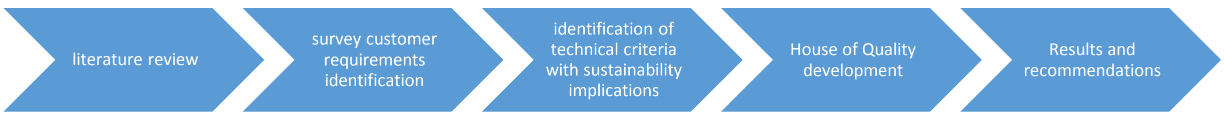


Figure 1. Research process diagram.

Source: Own elaboration.

The study began by identifying user requirements for smartphones. A survey questionnaire was designed to capture the needs and preferences of smartphone users. The target population consisted of 31 students aged 18 to 34 from the Silesian University of Technology in Poland. The questionnaire contained 20 multiple-choice questions, focusing on key factors such as smartphone features, functionality, and sustainability concerns. To maximize accessibility and response rate, the survey was distributed via email, Facebook, and WhatsApp. Participants rated their requirements on a Likert scale from 1 to 5, with 1 representing the least important and 5 representing the most important features. After the survey data was collected, it was analyzed to prioritize customer requirements. The ranking process focused on identifying critical smartphone attributes such as battery life, network performance, and ease of maintenance. The results of the analysis were used to determine the importance of each customer need, forming the basis for the subsequent technical specifications.

The HoQ matrix was employed to translate customer needs into technical specifications. The use of HoQ allowed for a structured evaluation of how well product designs meet customer expectations and enables prioritization of design elements that require improvement. This tool helps ensure that the product's design aligns with customer desires while optimizing quality.

Sustainability metrics such as energy efficiency, material reduction, and the use of recycled materials were embedded into the QFD process. The HoQ correlation matrix was used to examine how each technical requirement related to sustainable design features, ensuring that these concerns were effectively addressed in the product improvement process. This step ensured that sustainability was not only integrated into the design but also prioritized alongside other technical considerations.

The results of the analysis were used to draw conclusions regarding the technical specifications that best align with both customer preferences and sustainability goals. Recommendations were formulated to improve the design and quality of smartphones while enhancing their sustainability profile.

4. Results

The smartphone market is characterized by rapid technological advancement and frequent product upgrades, leading to significant environmental concerns such as high energy consumption, resource depletion, and electronic waste. With an estimated 86% of the global population using smartphones, the industry contributes substantially to climate change, primarily through manufacturing and disposal processes. Addressing these sustainability challenges is crucial for minimizing the environmental footprint of mobile phones. The growth of the global population and smartphone users from 2016 to 2022 is presented in Figure 2.

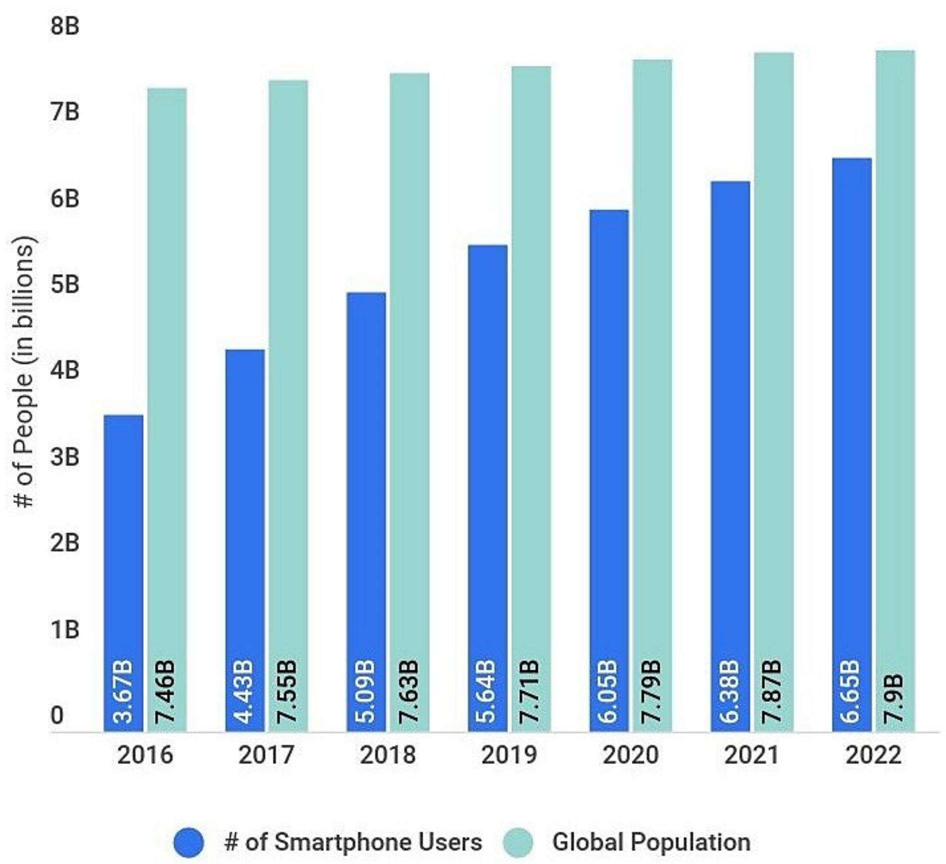


Figure 2. Growth of smartphone users.

Source: Flynn, 2022.

Customer Needs Identification

Customer requirements were identified through the survey, where participants rated features like battery life, network performance, and ease of maintenance. The survey results showed that Battery Life, Network Performance, and Touch Screen Sensitivity were the top priorities for customers. This input guided the initial phase of the QFD process, where customer needs (WHATs) were mapped out. The average value of importance based on customer feedback is presented in Figure 3. The features are ranked on a scale of 1 to 5.

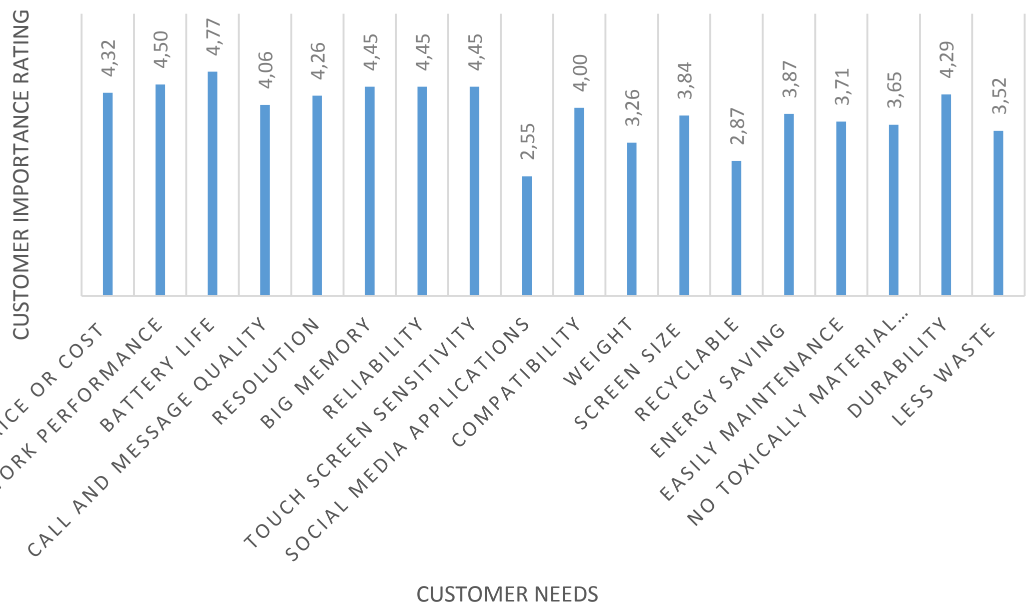


Figure 3. Customer importance rating.

Source: Own elaboration.

Design Requirements

The HoQ matrix was used to translate customer needs into technical specifications (HOWs). For example, the need for longer battery life was linked to technical requirements such as energy-saving capabilities and battery longevity. The relationship matrix classified the strength of connections between customer needs and technical features, using a 9-3-1 scale to indicate strong, moderate, or weak correlations. Table 1 provides technical characteristics for smartphones that could be tailored to meet the customer's needs.

Table 1.
Technical Characteristics for Smartphones

No.	Technical characteristics	Description
1	Rate of Recycled Material	What is the proportion of recycled materials used in the production of the smartphone?
2	Energy Saving	The smartphone's capacity to conserve energy through efficient power management and minimal power consumption.
3	Easily Maintenance	The ease of maintenance and repair of smartphones results in a reduced frequency of replacement and consequently, a decrease in waste generation.
4	Toxically Material Released	The quantity of hazardous substances employed in the production of the smartphone and the temporal context of its utilization.
5	Durability	The durability of a smartphone, as measured by its ability to withstand wear and tear, is positively correlated with its longevity and reduced frequency of replacement.
6	Reused Material	The quantity of reused material in the production of the smartphone.
7	Less Waste	The quantity of waste generated during the production and utilization of the smartphone.
8	Material Reduction	Reducing the quantity of resources utilized in the production of a smartphone.

Cont. table 1.

9	Battery Life	The duration of the smartphone's battery life is a crucial factor to consider in order to minimize the frequency of replacement.
10	Pollution Control	the measures used to minimize and regulate pollution both during the manufacturing of the smartphone and during usage.

Source: Own elaboration.

The relationship matrix between customer requirements and technical features is presented in Figure 4.

House Of Quality	Relationships: Strong=9 Medium=3 Weak=1			Technical Requirements (How)									
				Rate of Recycled Material	Energy Saving	Easily Maintenance	Toxically Material Released	Durability	Reused Material	Less Waste	Material Reduction	Battery Life	Pollution Control
Row		Customer Requirements (What)	Importance	1	2	3	4	5	6	7	8	9	10
1	Easy to use	Touch Screen Sensitivity	**4.45**	0	1	3	0	1	3	1	1	1	0
2		Social Media Applications	**2.55**	0	3	3	0	1	0	1	0	1	0
3		compatibility	**4.00**	0	1	0	0	3	0	3	0	0	0
4	Structure	Weight	**3.26**	1	9	3	0	1	3	1	3	0	0
5		Screen size	**3.84**	1	3	3	0	1	3	1	3	0	0
6	Performance	Network Performance	**4.50**	0	9	1	3	1	1	1	0	0	0
7		Battery Life	**4.77**	1	0	3	9	3	0	1	3	9	9
8		Calls and Messages quality	**4.06**	0	0	3	0	1	0	1	3	1	0
9		Resolution	**4.26**	0	3	3	0	1	0	1	0	0	0
10		Big memory	**4.45**	0	9	0	0	1	0	1	0	0	0
11		Reliability	**4.45**	0	9	3	0	9	0	1	3	3	0
12	Cost	Price or Cost	**4.32**	3	9	3	0	0	9	3	9	3	0

Figure 4. Customer-technical requirement matrix.

Source: Own elaboration.

Sustainability Considerations

Sustainability metrics, including energy efficiency, use of recycled materials, and waste reduction, were integrated into the QFD framework. Technical requirements such as the rate of recycled material, ease of maintenance, and pollution control were prioritized based on their potential to meet customer needs while minimizing environmental impact. For instance, the technical requirement "Energy Saving" was identified as a crucial factor, showing a strong correlation with customer demands for long battery life and reduced environmental impact.

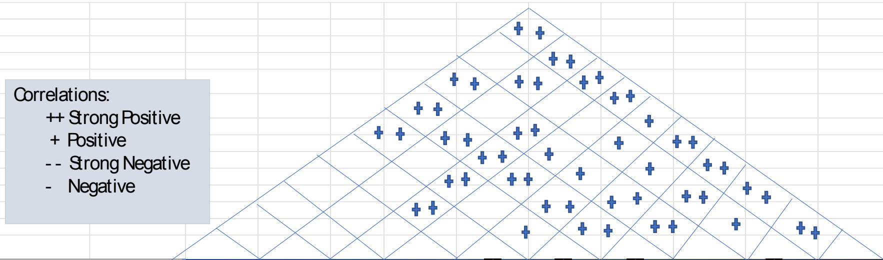
Analysis of Findings

The findings of this study align with and expand upon previous applications of Quality Function Deployment (QFD) in sustainable product design across various industries. The identification of Battery Life, Network Performance, and Touch Screen Sensitivity as top customer priorities is consistent with consumer expectations reported in prior research, emphasizing usability and efficiency as paramount features in sustainable mobile applications and product design (Alloghani, 2023; Russell et al., 2024). These results reaffirm the importance of aligning technical specifications with user needs in achieving both functional excellence and market appeal.

Notably, this study highlights the prioritization of energy-saving attributes, material reduction, and ease of maintenance—elements that reflect the growing emphasis on sustainability in the ICT sector. Similar findings have been observed in industries such as aviation and healthcare, where QFD has been used to maximize durability, simplify maintenance, and enhance lifecycle sustainability (Geng et al., 2024; Çetin, Üçler, 2023). However, this study distinguishes itself by integrating these attributes into the rapidly evolving smartphone sector, addressing challenges unique to high-turnover products, such as electronic waste and short product lifespans.

A key contribution of this research is its explicit focus on balancing customer satisfaction with sustainability goals. For instance, technical requirements like Energy Saving and Pollution Control were identified as critical not only for meeting customer expectations but also for minimizing environmental impact. This dual focus underscores the adaptability of QFD in addressing sustainability concerns in industries characterized by fast-paced innovation.

Compared to previous studies, this research provides a unique framework for applying QFD to consumer electronics. It demonstrates that sustainability metrics, such as the use of recycled materials and reduced waste, can be effectively embedded into the design process without compromising functionality. By bridging consumer needs with ecological priorities, this study offers a roadmap for manufacturers to innovate responsibly, setting a precedent for integrating QFD into other high-demand sectors. Figure 5 presents the final HoQ for smartphones.



Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)				▲	▲	▲	▼	▲	▲	▲	▲	▲	▲
House Of Quality		Relationships: Strong= 9 Medium= 3 Weak= 1		Technical Requirements (How): Rate of Recycled Material	Energy Saving	Easily Maintenance	Toxically Material Released	Durability	Reused Material	Less Waste	Material Reduction	Battery Life	Pollution Control
Row		Customer Requirements (What)	Importance	1	2	3	4	5	6	7	8	9	10
1	Easy to use	Touch Screen Sensitivity	4.45	0	1	3	0	1	3	1	1	1	0
2		Social Media Applications	2.55	0	3	3	0	1	0	1	0	1	0
3		compatibility	4.00	0	1	0	0	3	0	3	0	0	0
4	Structure	Weight	3.26	1	9	3	0	1	3	1	3	0	0
5		Screen size	3.84	1	3	3	0	1	3	1	3	0	0
6	Performance	Network Performance	4.50	0	9	1	3	1	1	1	0	0	0
7		Battery Life	4.77	1	0	3	9	3	0	1	3	9	9
8		Calls and Messages quality	4.06	0	0	3	0	1	0	1	3	1	0
9		Resolution	4.26	0	3	3	0	1	0	1	0	0	0
10		Big memory	4.45	0	9	0	0	1	0	1	0	0	0
11		Reliability	4.45	0	9	3	0	9	0	1	3	3	0
12	Cost	Price or Cost	4.32	3	9	3	0	0	9	3	9	3	0
		Absolute Importnce		24.83	229.22	112.38	56.43	97.73	78.03	65.55	104.47	80.30	42.93
		Relative Importance (%)		2.78	25.70	12.60	6.33	10.96	8.75	7.35	11.71	9.00	4.81
		Rank		10th	1th	2th	8th	4th	6th	7th	3th	5th	9th

Figure 5. The House of Quality (HoQ) for smartphones.

Source: Own elaboration.

Discussion

This study makes a unique contribution to the field of sustainable smartphone design by applying Quality Function Deployment (QFD) to directly integrate environmental attributes into customer-driven needs. By doing so, it establishes a structured framework that aligns consumer expectations with sustainability goals, a critical challenge in high-turnover consumer products like smartphones. Unlike previous studies that have primarily used QFD for durability and cost-effectiveness (Geng et al., 2024; Çetin, Üçler, 2023), this research focuses on incorporating sustainability metrics—such as energy efficiency, material reduction, and ease of maintenance—into the QFD process. This approach offers valuable insights for industries seeking to balance ecological responsibility with high consumer demand.

Prior research on QFD has highlighted its role in enhancing product durability and cost efficiency (Geng et al., 2024; Çetin, Üçler, 2023), primarily in industries like aviation and healthcare. Our research builds on these findings by tailoring QFD to address the unique challenges of smartphone design, where frequent product upgrades and high consumer expectations create sustainability dilemmas. In particular, while previous studies emphasize energy efficiency and material reduction, we introduce the concept of ease of maintenance as a critical technical attribute, which is often overlooked in the ICT sector. This new focus aligns with the growing importance of repairability and longevity in sustainable product design.

Our findings on energy-saving technical attributes are consistent with existing research that emphasizes carbon reduction and energy efficiency in sustainable design (Danushi et al., 2024; Remedios et al., 2023). However, the prioritization of ease of maintenance diverges from traditional priorities in the smartphone industry, which usually focus on performance and aesthetics. This shift in focus reflects a growing alignment with circular economy principles, as consumers increasingly demand repairable, long-lasting products. This divergence represents a new opportunity for the industry to adopt sustainability in a more holistic way.

The findings of this research validate our hypothesis that QFD can effectively integrate sustainability considerations into smartphone design without compromising functionality. Specifically, the study confirms that manufacturers can use QFD to systematically prioritize technical specifications that align with both market expectations and environmental responsibility. Our approach demonstrates that sustainability does not have to be an afterthought but can be embedded in the very foundation of product development, offering a model for manufacturers to follow.

Future research should explore the integration of artificial intelligence (AI) into the QFD process to enhance real-time analysis of customer feedback. This would enable more dynamic and adaptive prioritization of technical attributes, allowing manufacturers to respond more rapidly to consumer demands. Furthermore, we plan to expand the demographic scope of survey participants to include a more diverse sample, ensuring that our findings are more generalizable. Additionally, incorporating emerging sustainability metrics, such as carbon footprint and material lifecycle assessments, would further refine the QFD framework, making it more robust and applicable across different industries.

5. Conclusions

This research underscores the potential of Quality Function Deployment (QFD) as a strategic tool for integrating sustainability into smartphone design. By prioritizing attributes like energy efficiency, ease of maintenance, and material reduction, we provide a practical framework that can help manufacturers align their product development processes with both consumer demands and environmental goals. Our findings suggest that QFD can be used to address the challenges posed by high turnover rates and environmental impact in consumer electronics, offering a significant advantage in sustainable product design.

While this study contributes valuable insights, it also has limitations that must be acknowledged. The sample size of 31 student participants restricts the generalizability of our findings, particularly to a broader demographic. Moreover, while our application of QFD offers a promising approach to sustainable smartphone design, the model requires further refinement to fully address the complex and multidimensional aspects of sustainability. Future research should focus on expanding the sample size and exploring more diverse product categories to better understand the applicability of QFD in different contexts.

This study provides a foundation for future work on sustainable product design, offering insights that can be applied not only to smartphones but also to other industries facing similar sustainability challenges. For instance, industries like electronics, automotive, and consumer goods could benefit from the same QFD approach to integrate environmental responsibility into their product development processes. Our research also suggests that sustainability can be effectively incorporated into high-turnover products without sacrificing functionality, providing a pathway for industries to meet both consumer expectations and sustainability targets.

The broader impact of this research lies in its ability to offer a scalable framework for sustainable innovation in product design. By demonstrating how QFD can incorporate both ecological and functional perspectives, this study provides a valuable tool for manufacturers seeking to align their products with the principles of circular economy and sustainable development. Future practitioners and researchers can use these insights to refine QFD and develop more sustainable products, contributing to the broader objective of reducing environmental impact while meeting the needs of consumers.

The recommendations from this study on applying Quality Function Deployment (QFD) to sustainable product improvement in mobile phones underscore several strategic directions for manufacturers. Prioritizing energy efficiency is essential; smartphone manufacturers should focus on developing energy-saving features, such as advanced battery management systems and optimized power usage, to better align products with environmental objectives and meet consumer demand for sustainability. Enhancing material sustainability through the integration of recycled and biodegradable materials in smartphone production can reduce environmental waste and promote circular economy practices. This approach addresses ecological concerns and aligns with the growing demand for environmentally responsible products. Increasing customer awareness about sustainable smartphone usage and disposal practices is another key area. By educating consumers and launching awareness campaigns that emphasize eco-friendly features and end-of-life recycling options, manufacturers can foster a culture of environmental responsibility and promote a more sustainable lifecycle for their products. Adopting modular design for ease of maintenance is also recommended. A modular approach, which enables simple replacement of individual components, can extend device longevity and reduce the frequency of disposal, contributing significantly to sustainable lifecycle management. Finally, the consistent application of QFD in product development is recommended to integrate evolving customer needs and sustainability considerations effectively. By doing so, manufacturers can create products that better align with consumer expectations and environmental goals, enhancing both product appeal and ecological responsibility.

These recommendations provide a pathway for manufacturers to balance innovation with environmental stewardship, demonstrating the value of QFD in promoting sustainable development within the smartphone industry.

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A STUDY ON THE DISTANCES BETWEEN COMPANIES IN POLISH PROVINCES WITH RESPECT TO THE USE OF ICT RESOURCES AND COMPETENCIES

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Purpose: The aim of the paper is to employ the proposed taxonomic distance methods to investigate the level of the use of information and communication technology by enterprises in Polish provinces during the examined periods (during the Covid-19 pandemic).
Design/methodology/approach: The study examines the use of the Internet and information and communication technologies by enterprises in Polish provinces, with special emphasis placed on the Covid-19 pandemic period. Data were drawn from the Central Statistical Office, taking into account the thematic scope of the study and data availability. The study covered the years 2020-2022, including the time of the Covid-19 pandemic. Selected taxonomic methods were used in the analysis. In the first stage of the study, a synthetic variable was determined. The synthetic variable made it possible to compare the level of development of the phenomenon in selected provinces in 2022, 2021, 2020. Then, a distance matrix was determined. The distance between the level of development of the phenomenon separating Śląskie province from other provinces in the analyzed years was determined. The level of similarity of the Śląskie province to other provinces was examined (similarity matrix). In the last stage, the pace at which the Śląskie province became similar to other provinces in the analyzed period was examined.
Findings: The study analyzes internet and ICT usage by enterprises in the Polish provinces in the years 2020-2022, with special focus on the COVID-19 pandemic period. To sum up, comparative analysis performed by means of taxonomic methods can be an effective tool to study the elements of a complex process, can provide a broad picture of this process.
Research limitations/implications: The main limitation is the inability to collect a set of comparable data over many years. The final diagnostic data set included only 5 variables for two research topics.
Originality/value: The concept of comparative analysis of the phenomenon under consideration presented and implemented in this study can be applied to compare countries, using relevant measures, or to perform comparative analysis of other aspects of the issue, and the findings of these studies will contribute to further research in this area. The results of the proposed research methodology applied to explore the selected research problem and the set of data the study was based on can be used in the analyses of economic and socio-economic policies.
Keywords: taxonomic methods, Internet and ICT usage, COVID-19.
Category of the paper: Research paper.

1. Introduction

Recent years have seen dynamic development and transformation of ICT resources and competencies. In the beginning, the technologies that digitalization is based on included the use of the computer, laptop and smartphone and later extended to cloud-based technologies, robotization and artificial intelligence (Goban-Klas, Sienkiewicz, 1999). Socio-economic processes are becoming increasingly reliant on new technologies and so is the information society, which we have turned into, both in the public and private spheres. We can observe ongoing advances in IC technologies facilitating data collection, processing and transfer. What is more, the development of these technologies against a background of globalization contributes to the emergence and gradual transformation of an increasingly globalized information society. Globalization impacts on the creation of the information society and its evolution towards more advanced stages.

The literature offers a variety of definitions of the information society. L. Drelichowski defines it as: "… all the people who are able to communicate easily and widely and who have access to the necessary information which enhances living conditions, improves work performance as well as helps fulfill civic duties" (Drelichowski, 2001).

The coronavirus pandemic also brought about significant changes that contributed to the transformation of economies in numerous countries. Enterprises, public administration units, educational institutions, health care facilities, citizens, etc. faced both challenges and opportunities arising from the rapid introduction of remote work and remote communication, digitization of internal processes, acceleration of operations due to the use of the internet, etc. (Goban-Klas, Sienkiewicz, 1999). These developments have not only catapulted digital transformation but also provided employees with new convenient solutions, e.g. electronic document signing, electronic document circulation, video verification, biometric technologies, remote work management and remote task monitoring tools and software, data analysis systems, etc. (Śledziewska, Włoch, 2020; Gajewski et al., 2016).

The study analyzes internet and ICT usage by enterprises in the selected Poland's provinces in the years 2022-2020 with special focus on the COVID-19 pandemic period.

The aim of the paper is to employ the proposed taxonomic distance methods to investigate the level of the use of information and communication technology by enterprises in Poland during the examined periods.

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

The study examines the use of the Internet and information and communication technologies by enterprises in Polish provinces, with special emphasis placed on the Covid-19 pandemic period. Data were drawn from the Central Statistical Office, taking into account the thematic scope of the study and data availability. Proper measurement of the development level of the phenomenon in particular provinces of Poland requires selecting appropriate measures. However, there is a lack of universal information on the subject under consideration. The diagnostic variables adopted in the present study are measurable and best describe the development of the analysed phenomenon. Based on the calculated values of the coefficients of variation and the results of verifying correlation analysis conducted by means of an inverted correlation matrix, the final set of diagnostic characteristics which describes the phenomenon (Młodak, 2006; Panek, 2009; Zeliaś, 2004). Due to the lack of statistical data, it was necessary to reduce the thematic scope of the dataset. The final set of diagnostic variables was the basis for the analysis. The following set of variables was adopted in years: 2022, 2021, 2020 with particular focus on the times of the Covid-19 pandemic.

The set of features was composed taking into consideration both the thematic scope of the study and the availability of data. In addition, the features were divided according to the topical themes analysed for Polish provinces.

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

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

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

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

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

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

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

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

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

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

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

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

In describing the variables, the determination S – stimulant was introduced (Mika, 1995). The table 1 includes descriptive characteristics of the variables.

Table 1.
Basic descriptive characteristics of variables

	x_1	x_2	x_3	x_4	x_5	y_1	y_2	y_3	y_4	y_5
2022										
Vx	58.3	59.4	119.5	126.1	135	83.6	90.5	83.8	104.5	94.0
$\bar{x}$	6270.5	5360.3	150168.2	151648	121800	1451.3	1185.7	555.6	493.7	768.2
S	3652.5	3181.2	179470.9	191189	165058	1213.8	1073.2	465.8	515.8	722.2
2021										
Vx	20.6	21.1	21.7	29.5	25.8	83.6	90.5	83.8	104.4	94.0
$\bar{x}$	18026.9	15745.8	14372.7	4104.5	3264.4	1451.3	1185.7	555.6	493.7	768.2
S	3715.6	3333.9	3119.4	1213.8	843.6	1213.8	1073.2	465.8	515.8	722.2
2020										
Vx	89.6	132.0	66.0	67.3	68.5	89.6	98.6	101.4	102.5	91.1
$\bar{x}$	1242.9	128040.1	6697.4	5799.2	5320.2	1242.9	1066.3	561.6	876.1	574.8
S	1114.3	169001.6	4423.7	3900.7	3643.2	1114.3	1051.4	569.7	898.6	523.9

Source: based on own research.

3. Measuring distances between Polish provinces with respect to the level of the phenomenon under study

The first information about the synthetic variable can be found in the works of Z. Hellwig, who developed a method for presenting a complex phenomenon by means of one synthetic variable. Variables which describe a particular phenomenon are usually diverse in character, as there are both stimulants and destimulants among tchem (Mika, 1995).

The aim of the synthetic variable is to aggregate all the structure features of the variables that are used for its construction (Chomątowski, Sokołowski, 1978; Zeliaś, 2004; Strahl, 1990; Malina, 2008; Mika, 1995).

The analyzed set of diagnostic variables includes stimulants and destimulants, which have to be converted into stimulants according to formula (Zeliaś, 2004; Strahl, 1990):

$$x_{ijt}^{S} = 2\bar{\boldsymbol{x}} - x_{ijt}^{D}\ ,\ i = 1, \ldots, m;\ j = 1, \ldots, k;\ t = 1, \ldots, n, \tag{1}$$

where:

x_{ijt}^{D} - the value of the destimulant for the object i in time unit t,

x_{ijt}^{S} - the value of the stimulant for the object i in time unit t,

$\bar{\boldsymbol{x}}$ **-** weighted average of selected variable for countries,

k - the number of variables that make up the final set of variables,

m - the number of objects,

n - the number of time units.

A negative value of the stimulant for a given object indicates its unfavorable state. The next step involves normalizing variables by means of formula (Chomątowski, Sokołowski, 1978; Pociecha et al., 1988; Młodak, 2006; Panek, 2009; Zeliaś, 2004; Strahl, 1998; Malina, 2008):

$$S_{ijt} = \frac{x_{ijt}}{\sum_{i=1}^{m} x_{ijt}}, \tag{2}$$

where:

S_{ijt} - the value of the normalized *j*-th variable for object *i* in unit time *t,*

i = 1, …, *m; j* = 1, …, *k; t* = 1, …, *n.*

The transformation preserves the volatility of the variable and the measurement scale. Once the variables are normalized, we synthesize each of the selected groups of measures and calculate a synthetic variable (the arithmetic mean of the normalized variables).

4. Determination of a synthetic variable - an empirical example

Once the variables are normalized, we synthesize each of the selected groups of measures and calculate a synthetic variable. The values of the synthetic variable for the *i*-th province in time *t* are: $\boldsymbol{z_{it}}$ (t = 1,…,n, I = 1, …, m).

The analysis covered 16 provinces (m = 16), the time frame was 3 years (n = 3, 2022, 2021, 2020) and the number of variables was 5 (k = 5, variables listed in the previous chapter and two research topics). Table 2 shows the calculated values of the synthetic variable for selected provinces in the years analysed.

Table 2.
Determined values of the synthetic variable - variables related to access to the Internet by enterprises

Province	2020	2021	2022
Dolnośląskie	0.076	0.077	0.079
Kujawsko-pomorskie	0.043	0.048	0.039
Lubelskie	0.033	0.039	0.030
Lubuskie	0.024	0.024	0.019
Łódzkie	0.058	0.064	0.050
Małopolskie	0.092	0.098	0.095
Mazowiecki	0.223	0.156	0.258
Opolskie	0.020	0.020	0.018
Podkarpackie	0.043	0.043	0.037
Podlaskie	0.020	0.024	0.018
Pomorskie	0.067	0.068	0.066
Śląskie	0.118	0.134	0.111
Świętokrzyskie	0.020	0.022	0.020
Warmińsko-mazurskie	0.022	0.024	0.020
Wielkopolskie	0.106	0.120	0.112
Zachodniopomorskie	0.036	0.038	0.027

Source: based on own research.

The determined values of the synthetic variable describing the level of the analyzed phenomenon allow the countries to be ranked from the best to the worst. Table 3 shows the rank values assigned to the surveyed countries for the subsequent years analyzed.

Table 3.
Ranks of selected provinces during the examined periods - variables related to access to the Internet by enterprises

	Province	2020	2021	2022
1	Dolnośląskie	5	5	5
2	Kujawsko-pomorskie	8	8	8
3	Lubelskie	11	10	10
4	Lubuskie	12	14	14
5	Łódzkie	7	7	7
6	Małopolskie	4	4	4
7	Mazowieckie	1	1	1
8	Opolskie	16	16	16
9	Podkarpackie	9	9	9
10	Podlaskie	14	13	15
11	Pomorskie	6	6	6
12	Śląskie	2	2	3
13	Świętokrzyskie	15	15	13
14	Warmińsko-mazurskie	13	12	12
15	Wielkopolskie	3	3	2
16	Zachodniopomorskie	10	11	11

Source: based on own research.

Analyzing the selected set of variables (the first topic), we can see that Mazowieckie province in the years 2022, 2021, 2020 was always in the first place, and Opolskie province in the last place. The Śląskie province ranked second in terms of the development of the phenomenon in 2020 and 2021, and third in 2022.

Table 4.
Ranks of selected provinces during the examined periods- variables related to enterprises with Internet access buying cloud services

	Province	2020	2021	2022
1	Dolnośląskie	5	5	5
2	Kujawsko-pomorskie	8	8	8
3	Lubelskie	11	11	11
4	Lubuskie	12	12	12
5	Łódzkie	7	7	7
6	Małopolskie	3	4	4
7	Mazowiecki	1	1	1
8	Opolskie	13	13	13
9	Podkarpackie	9	10	10
10	Podlaskie	15	16	16
11	Pomorskie	6	6	6
12	Śląskie	2	2	2
13	Świętokrzyskie	14	15	15
14	Warmińsko-mazurskie	16	14	14
15	Wielkopolskie	4	3	3
16	Zachodniopomorskie	10	9	9

Source: based on own research.

Analyzing the results (second topic), we can see that the results are very similar. The Mazowieckie province is always in first place, and the Śląskie province in second place. The last place is taken by the Warmińsko-mazurskie province in 2020, and in 2021 and 2022 by the Podlaskie province.

5. Analysis of the level of similarity of development of the phenomenon

A multivariate comparative analysis is closely related to the quantitative disciplines. Taxonomic methods, which involve ordering a set of objects, are often employed to investigate research problems and research areas for which other tools cannot be applied.

Determining the distance between pairs of analyzed objects is a key element of the taxonomic analysis of multidimensional objects. A distance matrix provides a basis for comparing objects (countries). It is of the following form (Zeliaś, 2004; Malina, 2008):

$$D = \begin{bmatrix} d_{11} & \cdots & d_{1m} \\ \vdots & \ddots & \vdots \\ d_{m1} & \cdots & d_{mm} \end{bmatrix}, \quad (3)$$

where:

d_{ij} – the distance between *i*-th and *j*-th object (*i, j* = 1, …, *m*). (Matrix D is determined for the relevant year in the analyzed time interval, *t* = 1, …, *n*), respectively: d_{ij} = 0 - the compared objects are identical,

d_{ij}≠0 - the greater the value, the more dissimilar the objects are.

Matrix D allows for individual analysis of objects. The mutual position of objects can be described by means of a similarity or dissimilarity function (Zeliaś, 2004). The subject literature offers various distance measures, and this study applies – Chomątowski-Sokołowski measure (Młodak, 2006; Panek, 2009; Zeliaś, 2004).

The distance matrix was used to analyze the similarity of objects. The distance matrix was built, which provided a basis for the construction of the similarity matrix:

$$P = [p_{ij}]\ (i, j = 1, \ldots m),$$

where p_{ij} - measure of similarity between *i*-th and *j*-th object and: $p_{ij} \geq 0$, $p_{ij} = p_{ji}$, $p_{ij} = 1$ for *i* = *j*. This means a measure normalized, $p_{ij} \in < 0, 1 >$.

The similarity meter p_{ij} is determined according to the formula:

$$p_{ij} = \frac{d_{max} - d_{ij}}{d_{max}},\ (i,j = 1, \ldots, m) \quad (4)$$

where:

d_{ij} – the distance between *i*-th and *j*-th object, (*i,j* = 1, …, *m*),

d_{max} – the maximum distance of the Polish provinces from the reference object.

Similarity matrices between provinces determine the level of changes in the process of making pairs of provinces more similar or more distant from each other in the years under study.

In the last step of the analysis, the elements of the similarity matrix will be taken into account when examining changes in the level of similarity of provinces to each other.

Indicators of the intensity of changes in the process of provinces becoming similar to each other and to the model province are determined according to the formula:

$$w_{is} = \frac{1}{n}\sum_{t=2}^{n}(p_{is}^{t} - p_{is}^{t-1}) \ (i,\ s = 1,\ \ldots,\ m), \tag{5}$$

$$w'_{is} = \frac{1}{n}\sum_{t=2}^{n}\left|p_{is}^{t} - p_{is}^{t-1}\right| \ (i,\ s = 1,\ \ldots,\ m), \tag{6}$$

$$w''_{is} = \frac{1}{n}\sum_{t=2}^{n}\frac{\left|p_{is}^{t} - p_{is}^{t-1}\right|}{p_{is}^{t-1}} \cdot 100\% \ (i,\ s = 1,\ \ldots,\ m). \tag{7}$$

The value of the meter w_{is} with the (+) sign informs that the similarity is increasing, and the value with the (-) sign means that the objects are moving away from each other in the examined years. Small indicator values (w_{is}, w'_{is}) indicate small changes in the level of similarity between objects. The indicator w''_{is} determines the intensity of change.

6. A similarity matrix - an empirical example

We start the taxonomic analysis by constructing a three-dimensional data matrix $\boldsymbol{X} = [\boldsymbol{x_{ijt}}]$, k - the number of variables that make up the final set of variables (k = 5), m - the number of objects (m = 16), n - the number of time units (n = 3). Then we determine the normalized matrix according to the previously discussed theory. For each year, we calculate the distance matrix between the surveyed provinces. Table 5-10 presents the distance matrices between the analyzed provinces for the years: 2022, 2021, 2020.

In the first step, the distance matrices for the year 2022 and the two topics under consideration were presented.

Table 5.

Distance matrix - for the year 2022 - variables related to access to the Internet by enterprises

Province	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.00	0.20	0.25	0.06	0.15	0.08	0.89	0.31	0.21	0.31	0.07	0.16	0.30	0.30	0.16	0.26
2	0.20	0.00	0.05	0.10	0.05	0.28	1.09	0.11	0.02	0.11	0.13	0.36	0.10	0.10	0.36	0.06
3	0.25	0.05	0.00	0.59	0.10	0.33	1.14	0.06	0.04	0.06	0.18	0.40	0.05	0.05	0.41	0.01
4	0.06	0.10	0.59	0.00	0.03	0.38	1.19	0.01	0.09	0.01	0.23	0.46	0.00	0.00	0.46	0.04
5	0.15	0.05	0.10	0.03	0.00	0.05	1.04	0.16	0.07	0.16	0.08	0.30	0.15	0.15	0.31	0.11
6	0.08	0.28	0.33	0.38	0.05	0.00	0.81	0.39	0.29	0.39	0.15	0.08	0.38	0.38	0.08	0.34
7	0.89	1.09	1.14	1.19	1.04	0.81	0.00	1.20	1.11	1.20	0.19	0.74	1.19	1.19	0.73	1.15
8	0.31	0.11	0.06	0.01	0.16	0.39	1.20	0.00	0.10	0.01	0.24	0.46	0.01	0.01	0.47	0.05
9	0.21	0.02	0.04	0.09	0.07	0.29	1.11	0.10	0.00	0.09	0.15	0.37	0.09	0.09	0.37	0.05
10	0.31	0.11	0.06	0.01	0.16	0.39	1.20	0.01	0.09	0.00	0.24	0.46	0.01	0.01	0.47	0.05
11	0.07	0.13	0.18	0.23	0.08	0.15	0.19	0.24	0.15	0.24	0.00	0.22	0.23	0.23	0.23	0.19
12	0.16	0.36	0.40	0.46	0.30	0.08	0.74	0.46	0.37	0.46	0.22	0.00	0.45	0.45	0.05	0.42

Cont. table 5.

13	0.30	0.10	0.05	0.00	0.15	0.38	1.19	0.01	0.09	0.01	0.23	0.45	0.00	0.00	0.46	0.04
14	0.30	0.10	0.05	0.00	0.15	0.38	1.19	0.01	0.09	0.01	0.23	0.45	0.00	0.00	0.46	0.04
15	0.16	0.36	0.41	0.46	0.31	0.08	0.73	0.47	0.37	0.47	0.23	0.05	0.46	0.46	0.00	0.42
16	0.26	0.06	0.01	0.04	0.11	0.34	1.15	0.05	0.05	0.05	0.19	0.42	0.04	0.04	0.42	0.00

Source: based on own research.

Comparing the Śląskie province, we can notice that: the greatest distance separates the Śląskie province from the Mazowieckie province, and the smallest distance separates the Wielkopolskie province.

Table 6.

Distance matrix - for the year 2022 - variables related to enterprises with Internet access buying cloud services

Province	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.00	0.25	0.31	0.06	0.13	0.09	0.74	0.33	0.26	0.35	0.06	0.19	0.34	0.34	0.12	0.25
2	0.25	0.00	0.06	0.08	0.12	0.34	0.98	0.09	0.03	0.11	0.18	0.44	0.10	0.09	0.37	0.01
3	0.31	0.06	0.00	0.56	0.18	0.40	1.05	0.03	0.05	0.05	0.25	0.50	0.03	0.03	0.43	0.06
4	0.06	0.08	0.56	0.00	0.04	0.42	1.06	0.02	0.06	0.03	0.26	0.52	0.02	0.02	0.45	0.07
5	0.13	0.12	0.18	0.04	0.00	0.04	0.87	0.20	0.13	0.23	0.06	0.32	0.21	0.21	0.25	0.12
6	0.09	0.34	0.40	0.42	0.04	0.00	0.65	0.42	0.35	0.45	0.16	0.12	0.43	0.43	0.04	0.34
7	0.74	0.98	1.05	1.06	0.87	0.65	0.00	1.07	1.00	1.09	0.16	0.55	1.08	1.08	0.62	0.99
8	0.33	0.09	0.03	0.02	0.20	0.42	1.07	0.00	0.07	0.02	0.27	0.52	0.01	0.02	0.46	0.08
9	0.26	0.03	0.05	0.06	0.13	0.35	1.00	0.07	0.00	0.09	0.20	0.45	0.08	0.08	0.38	0.03
10	0.35	0.11	0.05	0.03	0.23	0.45	1.09	0.02	0.09	0.00	0.29	0.55	0.01	0.02	0.48	0.10
11	0.06	0.18	0.25	0.26	0.06	0.16	0.16	0.27	0.20	0.29	0.00	0.26	0.28	0.28	0.19	0.19
12	0.19	0.44	0.50	0.52	0.32	0.12	0.55	0.52	0.45	0.55	0.26	0.00	0.53	0.53	0.08	0.44
13	0.34	0.10	0.03	0.02	0.21	0.43	1.08	0.01	0.08	0.01	0.28	0.53	0.00	0.01	0.46	0.09
14	0.34	0.09	0.03	0.02	0.21	0.43	1.08	0.02	0.08	0.02	0.28	0.53	0.01	0.00	0.46	0.09
15	0.12	0.37	0.43	0.45	0.25	0.04	0.62	0.46	0.38	0.48	0.19	0.08	0.46	0.46	0.00	0.38
16	0.25	0.01	0.06	0.07	0.12	0.34	0.99	0.08	0.03	0.10	0.19	0.44	0.09	0.09	0.38	0.00

Source: based on own research.

Comparing the Śląskie province, we can notice that: the greatest distance separates the Śląskie province from the Podlaskie province, and the smallest distance separates the Wielkopolskie province.

Table 7.

Distance matrix - for the year 2021 - variables related to access to the Internet by enterprises

Province	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.00	0.14	0.19	0.05	0.06	0.10	0.39	0.28	0.17	0.26	0.05	0.28	0.28	0.26	0.21	0.20
2	0.14	0.00	0.04	0.12	0.08	0.25	0.54	0.14	0.03	0.12	0.10	0.43	0.13	0.12	0.36	0.05
3	0.19	0.04	0.00	0.61	0.13	0.29	0.58	0.09	0.02	0.07	0.14	0.47	0.09	0.07	0.40	0.02
4	0.05	0.12	0.61	0.00	0.04	0.37	0.66	0.02	0.09	0.01	0.22	0.55	0.01	0.01	0.48	0.07
5	0.06	0.08	0.13	0.04	0.00	0.03	0.46	0.22	0.11	0.20	0.03	0.35	0.21	0.20	0.28	0.13
6	0.10	0.25	0.29	0.37	0.03	0.00	0.29	0.39	0.28	0.37	0.15	0.18	0.38	0.37	0.11	0.30
7	0.39	0.54	0.58	0.66	0.46	0.29	0.00	0.68	0.57	0.66	0.09	0.12	0.67	0.66	0.18	0.59
8	0.28	0.14	0.09	0.02	0.22	0.39	0.68	0.00	0.11	0.02	0.24	0.57	0.01	0.02	0.50	0.09
9	0.17	0.03	0.02	0.09	0.11	0.28	0.57	0.11	0.00	0.09	0.12	0.46	0.11	0.09	0.39	0.04
10	0.26	0.12	0.07	0.01	0.20	0.37	0.66	0.02	0.09	0.00	0.22	0.55	0.01	0.01	0.48	0.07
11	0.05	0.10	0.14	0.22	0.03	0.15	0.09	0.24	0.12	0.22	0.00	0.33	0.23	0.22	0.26	0.15
12	0.28	0.43	0.47	0.55	0.35	0.18	0.12	0.57	0.46	0.55	0.33	0.00	0.56	0.55	0.07	0.48
13	0.28	0.13	0.09	0.01	0.21	0.38	0.67	0.01	0.11	0.01	0.23	0.56	0.00	0.01	0.49	0.08

Cont. table 7.

14	0.26	0.12	0.07	0.01	0.20	0.37	0.66	0.02	0.09	0.01	0.22	0.55	0.01	0.00	0.48	0.07
15	0.21	0.36	0.40	0.48	0.28	0.11	0.18	0.50	0.39	0.48	0.26	0.07	0.49	0.48	0.00	0.41
16	0.20	0.05	0.02	0.07	0.13	0.30	0.59	0.09	0.04	0.07	0.15	0.48	0.08	0.07	0.41	0.00

Source: based on own research.

Comparing the Śląskie province, we can notice that: the greatest distance separates the Śląskie province from the Opolskie province, and the smallest distance separates the Wielkopolskie province.

Table 8.
Distance matrix - for the year 2021 - variables related to enterprises with Internet access buying cloud services

Province	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.00	0.25	0.31	0.06	0.13	0.09	0.74	0.33	0.26	0.35	0.06	0.19	0.34	0.34	0.12	0.25
2	0.25	0.00	0.06	0.08	0.12	0.34	0.98	0.09	0.03	0.11	0.18	0.44	0.10	0.09	0.37	0.01
3	0.31	0.06	0.00	0.56	0.18	0.40	1.05	0.03	0.05	0.05	0.25	0.50	0.03	0.03	0.43	0.06
4	0.06	0.08	0.56	0.00	0.04	0.42	1.06	0.02	0.06	0.03	0.26	0.52	0.02	0.02	0.45	0.07
5	0.13	0.12	0.18	0.04	0.00	0.04	0.87	0.20	0.13	0.23	0.06	0.32	0.21	0.21	0.25	0.12
6	0.09	0.34	0.40	0.42	0.04	0.00	0.65	0.42	0.35	0.45	0.16	0.12	0.43	0.43	0.04	0.34
7	0.74	0.98	1.05	1.06	0.87	0.65	0.00	1.07	1.00	1.09	0.16	0.55	1.08	1.08	0.62	0.99
8	0.33	0.09	0.03	0.02	0.20	0.42	1.07	0.00	0.07	0.02	0.27	0.52	0.01	0.02	0.46	0.08
9	0.26	0.03	0.05	0.06	0.13	0.35	1.00	0.07	0.00	0.09	0.20	0.45	0.08	0.08	0.38	0.03
10	0.35	0.11	0.05	0.03	0.23	0.45	1.09	0.02	0.09	0.00	0.29	0.55	0.01	0.02	0.48	0.10
11	0.06	0.18	0.25	0.26	0.06	0.16	0.16	0.27	0.20	0.29	0.00	0.26	0.28	0.28	0.19	0.19
12	0.19	0.44	0.50	0.52	0.32	0.12	0.55	0.52	0.45	0.55	0.26	0.00	0.53	0.53	0.08	0.44
13	0.34	0.10	0.03	0.02	0.21	0.43	1.08	0.01	0.08	0.01	0.28	0.53	0.00	0.01	0.46	0.09
14	0.34	0.09	0.03	0.02	0.21	0.43	1.08	0.02	0.08	0.02	0.28	0.53	0.01	0.00	0.46	0.09
15	0.12	0.37	0.43	0.45	0.25	0.04	0.62	0.46	0.38	0.48	0.19	0.08	0.46	0.46	0.00	0.38
16	0.25	0.01	0.06	0.07	0.12	0.34	0.99	0.08	0.03	0.10	0.19	0.44	0.09	0.09	038	0.00

Source: based on own research.

Comparing the Śląskie province, we can notice that: the greatest distance separates the Śląskie province from the Podlaskie province, and the smallest distance separates the Wielkopolskie province.

The latest distance matrices for 2020.

Table 9.
Distance matrix - for the year 2020 - variables related to access to the Internet by enterprises

Province	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.00	0.16	0.21	0.05	0.09	0.09	0.74	0.28	0.16	0.28	0.05	0.21	0.28	0.27	0.15	0.20
2	0.16	0.00	0.05	0.10	0.07	0.24	0.90	0.12	0.02	0.12	0.12	0.37	0.12	0.11	0.31	0.03
3	0.21	0.05	0.00	0.58	0.12	0.30	0.95	0.07	0.05	0.06	0.17	0.42	0.06	0.06	0.37	0.02
4	0.05	0.10	0.58	0.00	0.03	0.34	1.00	0.02	0.10	0.02	0.21	0.47	0.02	0.02	0.41	0.06
5	0.09	0.07	0.12	0.03	0.00	0.03	0.83	0.19	0.07	0.19	0.05	0.30	0.19	0.18	0.24	0.11
6	0.09	0.24	0.30	0.34	0.03	0.00	0.66	0.36	0.25	0.36	0.13	0.13	0.36	0.35	0.07	0.28
7	0.74	0.90	0.95	1.00	0.83	0.66	0.00	1.02	0.90	1.01	016	0.53	1.02	1.01	0.59	0.93
8	0.28	0.12	0.07	0.02	0.19	0.36	1.02	0.00	0.12	0.01	0.24	0.49	0.01	0.02	0.43	0.08
9	0.16	0.02	0.05	0.10	0.07	0.25	0.90	0.12	0.00	0.11	0.12	0.37	0.11	0.11	0.32	0.04
10	0.28	0.12	0.06	0.02	0.19	0.36	1.01	0.01	0.11	0.00	0.23	0.49	0.00	0.01	0.43	0.08
11	0.05	0.12	0.17	0.21	0.05	0.13	0.16	0.24	0.12	0.23	0.00	0.26	0.23	0.23	0.20	0.15
12	0.21	0.37	0.42	0.47	0.30	0.13	0.53	0.49	0.37	0.49	0.26	0.00	0.49	0.48	0.08	0.41
13	0.28	0.12	0.06	0.02	0.19	0.36	1.02	0.01	0.11	0.00	0.23	0.49	0.00	0.01	0.43	0.08

Cont. table 9.

14	0.27	0.11	0.06	0.02	0.18	0.35	1.01	0.02	0.11	0.01	0.23	0.48	0.01	0.00	0.42	0.07
15	0.15	0.31	0.37	0.41	0.24	0.07	0.59	0.43	0.32	0.43	0.20	0.08	0.43	0.42	0.00	0.35
16	0.20	0.03	0.02	0.06	0.11	0.28	0.93	0.08	0.04	0.08	0.15	0.41	0.08	0.07	0.35	0.00

Source: based on own research.

Comparing the Śląskie province, we can notice that: the greatest distance separates the Śląskie province from the Mazowieckie province, and the smallest distance separates the Wielkopolskie province.

Table 10.
Distance matrix - for the year 2020 - variables related to enterprises with Internet access buying cloud services

Province	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0.00	0.22	0.27	0.06	0.13	0.09	0.88	0.33	0.23	0.35	0.07	0.16	0.34	0.35	0.04	0.25
2	0.22	0.00	0.06	0.08	0.08	0.30	1.10	0.11	0.04	0.13	0.14	0.37	0.12	0.14	0.25	0.04
3	0.27	0.06	0.00	0.57	0.13	0.35	1.15	0.06	0.04	0.08	0.19	0.42	0.07	0.09	0.30	0.04
4	0.06	0.08	0.57	0.00	0.03	0.38	1.18	0.03	0.07	0.05	0.22	0.45	0.04	0.06	0.33	0.05
5	0.13	0.08	0.13	0.03	0.00	0.04	1.02	0.20	0.10	0.21	0.07	0.29	0.20	0.22	0.17	0.12
6	0.09	0.30	0.35	0.38	0.04	0.00	0.80	0.41	0.31	0.43	0.15	0.08	0.42	0.43	0.08	0.33
7	0.88	1.10	1.15	1.18	1.02	0.80	0.00	1.21	1.11	1.23	0.19	0.72	1.22	1.23	0.85	1.13
8	0.33	0.11	0.06	0.03	0.20	0.41	1.21	0.00	0.10	0.02	0.26	0.49	0.02	0.02	0.36	0.08
9	0.23	0.04	0.04	0.07	0.10	0.31	1.11	0.10	0.00	0.12	0.16	0.39	0.10	0.12	0.27	0.05
10	0.35	0.13	0.08	0.05	0.21	0.43	1.23	0.02	0.12	0.00	0.27	0.50	0.01	0.01	0.38	0.09
11	0.07	0.14	0.19	0.22	0.07	0.15	0.19	0.26	0.16	0.27	0.00	0.23	0.26	0.28	0.11	0.18
12	0.16	0.37	0.42	0.45	0.29	0.08	0.72	0.49	0.39	0.50	0.23	0.00	0.49	0.51	0.12	0.41
13	0.34	0.12	0.07	0.04	0.20	0.42	1.22	0.02	0.10	0.01	0.26	0.49	0.00	0.02	0.37	0.08
14	0.35	0.14	0.09	0.06	0.22	0.43	1.23	0.02	0.12	0.01	0.28	0.51	0.02	0.00	0.39	0.10
15	0.04	0.25	0.30	0.33	0.17	0.08	0.85	0.36	0.27	0.38	0.11	0.12	0.37	0.39	0.00	0.29
16	0.25	0.04	0.04	0.05	0.12	0.33	1.13	0.08	0.05	0.09	0.18	0.41	0.08	0.10	0.29	0.00

Source: based on own research.

Comparing the Śląskie province, we can notice that: the greatest distance separates the Śląskie province from the Mazowieckie province, and the smallest distance separates the Małopolskie province.

In the next step of the analysis, similarity matrices were determined.

Table 11.
Similarity matrix - for the year 2022 - variables related to access to the Internet by enterprises

Province	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.00	0.91	0.89	0.97	0.93	0.96	0.60	0.86	0.91	0.86	0.97	0.93	0.87	0.87	0.93	0.88
2	0.91	1.00	0.98	0.96	0.98	0.88	0.51	0.95	0.99	0.95	0.94	0.84	0.96	0.96	0.84	0.97
3	0.89	0.98	1.00	0.74	0.95	0.85	0.49	0.97	0.98	0.97	0.92	0.82	0.98	0.98	0.82	0.99
4	0.97	0.96	0.74	1.00	0.99	0.83	0.47	1.00	0.96	1.00	0.90	0.80	1.00	1.00	0.79	0.98
5	0.93	0.98	0.95	0.99	1.00	0.98	0.54	0.93	0.97	0.93	0.96	0.87	0.93	0.93	0.86	0.95
6	0.96	0.88	0.85	0.83	0.98	1.00	0.64	0.83	0.87	0.83	0.93	0.96	0.83	0.83	0.96	0.85
7	0.60	0.51	0.49	0.47	0.54	0.64	1.00	0.46	0.51	0.46	0.91	0.67	0.47	0.47	0.67	0.48
8	0.86	0.95	0.97	1.00	0.93	0.83	0.46	1.00	0.96	1.00	0.89	0.79	1.00	0.99	0.79	0.98
9	0.91	0.99	0.98	0.96	0.97	0.87	0.51	0.96	1.00	0.96	0.93	0.84	0.96	0.96	0.83	0.98
10	0.86	0.95	0.97	1.00	0.93	0.83	0.46	1.00	0.96	1.00	0.89	0.79	1.00	1.00	0.79	0.98
11	0.97	0.94	0.92	0.90	0.96	0.93	0.91	0.89	0.93	0.89	1.00	0.90	0.90	0.90	0.90	0.91
12	0.93	0.84	0.82	0.80	0.87	0.96	0.67	0.79	0.84	0.79	0.90	1.00	0.80	0.80	0.98	0.81
13	0.87	0.96	0.98	1.00	0.93	0.83	0.47	1.00	0.96	1.00	0.90	0.80	1.00	1.00	0.79	0.98

Cont. table 11.

14	0.87	0.96	0.98	1.00	0.93	0.83	0.47	0.99	0.96	1.00	0.90	0.80	1.00	1.00	0.79	0.98
15	0.93	0.84	0.82	0.79	0.86	0.96	0.67	0.79	0.83	0.79	0.90	0.98	0.79	0.79	1.00	0.81
16	0.88	0.97	0.99	0.98	0.95	0.85	0.48	0.98	0.98	0.98	0.91	0.81	0.98	0.98	0.81	1.00

Source: based on own research.

Table 12.

Similarity matrix - for the year 2022 - variables related to enterprises with Internet access buying cloud services

Province	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1.00	0.89	0.86	0.97	0.94	0.96	0.67	0.85	0.88	0.84	0.97	0.91	0.85	0.85	0.94	0.89
2	0.89	1.00	0.97	0.97	0.95	0.85	0.56	0.96	0.98	0.95	0.92	0.80	0.96	0.96	0.83	0.99
3	0.86	0.97	1.00	0.75	0.92	0.82	0.53	0.99	0.98	0.98	0.89	0.78	0.99	0.99	0.81	0.97
4	0.97	0.97	0.75	1.00	0.98	0.81	0.52	0.99	0.97	0.99	0.88	0.77	0.99	0.99	0.80	0,97
5	0.94	0.95	0.92	0.98	1.00	0.98	0.61	0.91	0.94	0.90	0.97	0.86	0.90	0.90	0.89	0.94
6	0.96	0.85	0.82	0.81	0.98	1.00	0.71	0.81	0.84	0.80	0.93	0.95	0.81	0.81	0.98	0.85
7	0.67	0.56	0.53	0.52	0.61	0.71	1.00	0.52	0.55	0.51	0.93	0.76	0.52	0.52	0.72	0.56
8	0.85	0.96	0.99	0.99	0.91	0.81	0.52	1.00	0.97	0.99	0.88	0.77	0.99	0.99	0.80	0.96
9	0.88	0.98	0.98	0.97	0.94	0.84	0.55	0.97	1.00	0.96	0.91	0.80	0.96	0.96	0.83	0.99
10	0.84	0.95	0.98	0.99	0.90	0.80	0.51	0.99	0.96	1.00	0.87	0.76	0.99	0.99	0.79	0.95
11	0.97	0.92	0.89	0.88	0.97	0.93	0.93	0.88	0.91	0.87	1.00	0.89	0.88	0.88	0.92	0.92
12	0.91	0.80	0.78	0.77	0.86	0.95	0.76	0.77	0.80	0.76	0.89	1.00	0.76	0.76	0.97	0.80
13	0.85	0.96	0.99	0.99	0.90	0.81	0.52	0.99	0.96	0.99	0.88	0.76	1.00	1.00	0.79	0.96
14	0.85	0.96	0.99	0.99	0.90	0.81	0.52	0.99	0.96	0.99	0.88	0.76	1.00	1.00	0.79	0.96
15	0.94	0.83	0.81	0.80	0.89	0.98	0.72	0.80	0.83	0.79	0.92	0.97	0.79	0.79	1.00	0.83
16	0.89	0.99	0.97	0.97	0.94	0.85	0.56	0.96	0.99	0.95	0.92	0.80	0.96	0.96	0.83	1.00

Source: based on own research.

(The determined matrices take up many pages of the article, which does not allow presenting all of them, therefore the values of the measures of similarity of the Śląskie province to other provinces in the examined years are presented) The designated matrices make it possible to examine changes in the process of provinces becoming similar or moving away from similarity in the examined years.

Table 13.

Similarity matrix for Ślaskie province - 2022, 2021, 2020 - variables related to access to the Internet by enterprises

Province	2022	2021	2020
	Śląskie		
Dolnośląskie	0.930	0.873	0.906
Kujawsko-pomorskie	0.841	0.808	0.834
Lubelskie	0.819	0.788	0.811
Lubuskie	0.796	0.754	0.790
Łódzkie	0.865	0.845	0.865
Małopolskie	0.962	0.920	0.943
Mazowieckie	0.670	0.944	0.764
Opolskie	0.793	0.746	0.781
Podkarpackie	0.836	0.796	0.833
Podlaskie	0.794	0.755	0.782
Pomorskie	0.901	0.852	0.886
Śląskie	1.000	1.000	1.000
Świętokrzyskie	0.797	0.749	0.782
Warmińsko-mazurskie	0.797	0.755	0.785

cont. table 13.

Wielkopolskie	0.977	0.969	0.966
Zachodniopomorskie	0.814	0.785	0.818

Source: based on own research.

The highest level of similarity of Śląskie province is to Wielkopolskie province in the analyzed years. The Śląskie province became more and more similar to the Wielkopolskie province in terms of the analyzed characteristics (the value of the measure systematically increases).

The lowest values occur for the Mazowieckie province in the level of similarity to the Śląskie province.

To assess the level of changes in the process of resemblance of Śląskie province to other provinces, the following indicators have been established:

Table 14.
Indicators of the intensity of changes in the level of similarity of the Śląskie province to other provinces - variables related to access to the Internet by enterprises

Province	w_{is}	w'_{is}	w''_{is}(%)
Dolnośląskie	0.0121	0.0454	5.1338
Kujawsko-pomorskie	0.0037	0.0293	3.5828
Lubelskie	0.0043	0.0270	3.3922
Lubuskie	0.0031	0.0387	5.0283
Łódzkie	-0.0001	0.0209	2.4403
Małopolskie	0.0097	0.0329	3.5434
Mazowieckie	-0.0470	0.2270	26.2915
Opolskie	0.0060	0.0409	5.3737
Podkarpackie	0.0013	0.0383	4.7089
Podlaskie	0.0058	0.0331	4.3192
Pomorskie	0.0075	0.0416	4.8069
Śląskie	0.0000	0.0000	0.0000
Świętokrzyskie	0.0074	0.0405	5.3128
Warmińsko-mazurskie	0.0062	0.0360	4.6932
Wielkopolskie	0.0056	0.0056	0.5789
Zachodniopomorskie	-0.0020	0.0313	3.9030

Source: based on own research.

The value of the meter w_{is} with the sign (+) indicates an increase in the similarity of the analyzed provinces (in 2022, 2021, 2020). For the Mazowieckie province the value of the indicator is negative and amounts to 26.3%. This means that there is no process of becoming similar to the analyzed phenomenon. For Zachodniopomorskie and Łódzkie provinces the indicators are negative and values are very small and amount to 3.9%, 2.4% (w''_{is}) (A negative sign for these provinces may mean that their process of becoming similar to the model province was faster than that of the Śląskie province). The highest value of the indicator (w''_{is}) determining the rate of change in the Śląskie province becoming similar to the Opolskie province, and the lowest rate of change in the Śląskie province becoming similar to Wielkopolskie province in 2022, 2021, 2020.

7. Conclusion

The aim of the paper was to employ the taxonomic methods to investigate the level of the use of information and communication technology by enterprises in Poland during the examined periods.

The study covered the years 2022, 2021, 2020, including the time of the Covid-19 pandemic. Selected taxonomic methods were used in the analysis. In the first step of the study, a synthetic variable was determined.

The synthetic variable can present a complex phenomenon by means of one variable. Variables which describe a particular phenomenon are usually diverse in character, as there are both stimulants and destimulants. The synthetic variable presented the level of development of the analyzed phenomenon in Polish provinces in selected years. The values of the synthetic variable additionally allowed for ranking the provinces from the best to the worst in terms of the studied phenomenon. The Mazowieckie province had the highest level throughout the period under study (The richest province in Poland is Mazowieckie province due to the capital of Poland).

Then the distance matrix was determined in 2022, 2021, 2020 for two research topics. The distance of the level of development of the phenomenon that separates Śląskie province from the studied provinces has been determined.

The distance matrices also contain information on the distances between each of the selected Polish provinces in the analysis. Distance matrices determined the distance in the development of the phenomenon that separates the selected province from other subsequent provinces.

Then, a similarity matrix was determined to examine the level of similarity of the Śląskie province to other provinces for the analyzed years (for two research topics).

Taking into account the similarity matrix, it was possible to determine the indicators of the rate of similarity in the development of the phenomenon over the entire period of time considered.

To sum up, the taxonomic analysis tools selected in the analysis made it possible to study the phenomenon both in one year and for three years in total. The synthetic variable presented the level of development of the phenomenon in each province individually and assigned ranks for provinces. The distance matrix presented the distance in the development of the phenomenon of the Śląskie province from other provinces. And the similarity matrix allowed for the determination of measures of the pace of development of the Śląskie province becoming more similar to the remaining provinces in the period under study.

To sum up, it can be said that digital transformation is implemented by enterprises, public administration, society and the national economy. Digitization has a significant impact on consumer behavior, changes the rules of competition in the market and creates new economic models. Today's organizations, businesses, society and economy must respond quickly to the changing environment and implement appropriate, effective solutions to survive.

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IMPACT OF ARTIFICIAL INTELLIGENCE INNOVATIONS ON THE LABOR MARKET OF THE EUROPEAN UNION

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Purpose: The aim of this article is to examine whether the use of artificial intelligence by enterprises affects the level of unemployment. Three research questions were posed: RQ1: Is there a statistically significant relationship between R&D expenditure and the unemployment rate? RQ2: Is there a statistically significant relationship between R&D expenditure and the level of AI technology usage? RQ3: Is there a relationship between the use of AI technology by enterprises and the unemployment rate?
Design/methodology/approach: The study considered three variables: the level of AI technology usage in enterprises, the level of unemployment, and the expenditure on research and development (R&D) in individual EU countries. The research area selected is the countries of the European Union. Statistical data available on the Eurostat website www.ec.europa.eu were used for the calculations.
Findings: The presented study did not show a statistically significant correlation between R&D expenditures of individual EU countries and their unemployment rates. However, it confirmed an inversely proportional relationship between R&D expenditures and the level of AI technology usage. No link was found between AI exposure and a decrease in employment in EU countries.
Research limitations/implications: The study's findings are limited by the exclusive use of statistical data from Eurostat and the focus on EU countries, which may not capture the full range of factors influencing the relationship between AI technology usage and unemployment globally.
Practical implications: Policymakers and business leaders in the EU should consider that while increased R&D expenditure may enhance AI technology usage, it does not directly correlate with higher unemployment rates, suggesting that investments in AI can be pursued without immediate concern for increasing technological unemployment
Originality/value: This paper provides new insights into the relationship between R&D expenditure, AI technology usage, and unemployment in EU countries, offering valuable information for policymakers and researchers interested in the economic impacts of AI adoption.
Keywords: Artifical Intelligence (AI), the level of unemployment, labor market, European Union.
Category of the paper: Research paper.

1. Introduction

The rapid increase in interest in the use of artificial intelligence (AI) worldwide raises numerous questions about the impact of this technology on the economy and the economy's ability to adapt to modern AI solutions. The extent of this increase can be demonstrated, among other things, by the number of patents filed in recent years for AI-based solutions. In 2021, as many as 141,240 patents were filed worldwide, more than 30 times the number in 2015 (HAI, 2022, p. 36). The development of the AI market offers organizations the opportunity to increase productivity, improve supply chain efficiency, and enhance customer satisfaction. However, this also raises several concerns. The primary concerns are related to recruitment processes in companies. On one hand, companies are unsure if they can keep up with the demand for AI-skilled labor. On the other hand, there is the question of whether the widespread adoption of AI solutions will drastically reduce the demand for workers, thereby significantly worsening the living standards of many people.

The aim of this article is to investigate whether the use of AI by enterprises affects the level of unemployment. The research area selected is the European Union countries. The calculations were performed using statistical data available on the Eurostat website www.ec.europa.eu.

The topic of AI has also been frequently addressed by scientists. Particularly in recent years, there has been a significant increase in interest. The number of publications found in the Web of Science database under the term "artificial intelligence" was 602 in 2000, 1398 in 2010, and as many as 23,964 in 2022. This group includes publications dedicated to the relationship between AI technology and unemployment levels in current market conditions. However, they primarily focused on new trends in the labor market and the links between the rapid implementation of AI technology and the demand for workers with specific skills and competencies. This study extends existing scientific research on artificial intelligence by presenting the results of research on the correlation between the number of enterprises using AI technology and the level of unemployment in a given country.

2. Literature review

The concern regarding technological unemployment has been known to humanity for a long time. Predictions about unemployment caused by the replacement of human labor with machines were already presented by J.M. Keynes in 1930 (2021, p. A12). His fears that technological development would lead to an increase in the percentage of unemployed people in the 20th century were not confirmed. However, artificial intelligence is a technology that far exceeds previous scientific achievements. In general terms, this concept refers to a not yet existing computer software that can fully think and act independently. In a narrower sense, artificial intelligence refers to such computer software that uses special algorithmic techniques to find patterns in data and predict future events related to the presented data (Raj, Seamans, 2019, p. 3). The fundamental difference between previous technologies and artificial intelligence is that previous (traditional) algorithms are programmed to perform a task, whereas an AI algorithm is programmed to learn how to perform the task (Bordot, 2022, p. 118).

According to the Artificial Intelligence Index Report 2022 created at Stanford University (HAI, 2022, p. 19), publications related to AI technology produced between 2010 and 2021 were mainly focused on pattern recognition (e.g., Alawneh et al., 2022; Amiri et al., 2022; Song, Fan, 2022), machine learning (e.g., Kuntz and Wilson 2022; Olugbade et al. 2022; Krajcer 2022), computer vision (e.g., Kitaguchi, 2022; Corke et al., 2022; Gumbs et al., 2022), algorithms (e.g., Zhu, Jing, 2022; Ma et al., 2022; Long, Gao, 2022), data mining (Huang et al., 2022; Cai et al., 2022), natural language processing (e.g., Moranding et al., 2022; Shaik et al., 2022), and human-computer interaction (e.g., Shao, 2022; Balmcombe, De Leo, 2022).

As mentioned in the introduction, the topic of the correlation between AI development and unemployment has also been addressed by scientists. In the Web of Science database, a total of 37 entries dedicated to both artificial intelligence and unemployment were found (search path: "artificial intelligence" AND "unemployment," author keywords), of which only 19 entries were published between 2020-2022 (5 in 2020, 8 in 2021, and 6 in 2022). After a literature review, it was found that only 10 publications actually address the impact of AI use on unemployment. The authors' views are presented in Table 1.

Table 1.
Impact of AI on unemployment levels in selected publications

Source	Does AI affect unemployment levels, and if so, how?
G. Kohli (2020)	It will increase the number of jobs as long as employees are continuously educated in new technologies.
W. Naude (2021)	In the short term, it does not increase unemployment, but such an increase is possible in the long term.
J. Mutascu (2021)	With low inflation, it increases unemployment; otherwise, there is no impact.
G. Anakpo, U. Kollamparambil (2022)	No negative impact was found. Further investments in robotics are recommended.
F. Fossen, A. Sorgner (2022)	It has an impact, the direction of which depends on the type of AI solution. Technologies that displace workers contribute to increased unemployment, while technologies that augment the workforce improve employee productivity and thereby positively affect their position in the labor market.
F. Santoni de Sio, T. Almeida, J. van den Hoven (2022)	It is predicted to have an impact. There is no definitive statement on what that impact will be.
F. Bordot (2022)	Increases unemployment.
D. Bailey (2022)	It will increase unemployment (the author focuses on the negatives in the article).
C. Lu, Chia-Hui Lu. (2022)	Decreases unemployment.
V. Nguyen (2022)	Increases unemployment up to a certain inflation threshold, then decreases it.

Source: Own study.

The opinions of researchers are presented chronologically in Table 1, based on the publication date of the articles. As seen, views on the impact of AI technology on employment levels are very divided. According to some experts, artificial intelligence will create more jobs than the market demands. However, for this to happen, people must continuously improve their education to keep up with the ever-evolving technology (Kohli, 2020). The positive impact of artificial intelligence on the job market is also noted by C. Lu and Chia-Hui Lu (2022) and G. Anakpo and U. Kollamparambil (2022). W. Naude (2021) believes that in the short term, AI will not increase unemployment, but emphasizes that such an increase is possible in the long term. Some researchers link the impact of AI on unemployment rates to the level of inflation (Mutascu, 2021; Nguyen, 2022). F. Fossen and A. Sorgner (2022) argue that the type of AI solutions used in organizations is crucial in this matter: some may lead to the creation of new jobs, while others will increase unemployment. F. Bordot (2022) and D. Bailey (2022) present the negative impact of AI on employment levels, whereas F. de Sio, T. Almeida, and J. van den Hoven do not definitively state whether and how artificial intelligence will correlate with unemployment rates.

E. Felten et al. (2019) also studied the impact of AI on employment levels. They created the AIOI index to measure the relationship between artificial intelligence and wages, employment, and labor market polarization. Their research showed that between 2012 and 2019, in occupations strongly related to computer use, greater use of AI technology translated into higher employment growth. Conversely, in the overall analyzed professions, no clear relationship was found between the use of artificial intelligence and employment levels. Thus, the research disproved the notion that the development of AI technology causes an increase in unemployment.

M. Thomas (2022) points out the increasing presence of artificial intelligence technology in human life. This is particularly evident in the following sectors: manufacturing, healthcare, education, media, customer service, and transportation. The development of AI is associated with the emergence of new professions and jobs requiring employees to have knowledge and skills directly related to this technology. In 2021, as many as 3.3% of all job advertisements in the IT sector in the USA were directly related to AI (HAI, 2022, p. 147). According to the AI employment index created by LinkedIn in 2021, the countries most frequently employing in the AI sector are New Zealand, Hong Kong, Ireland, Luxembourg, and Sweden. The percentage of LinkedIn-registered individuals with AI skills who started working for a company specializing in AI technology during the studied period was 2.42%, 1.56%, 1.28%, 1.26%, and 1.24%, respectively (HAI, 2022, p. 142).

3. Methodology

The aim of this article is to examine whether the use of artificial intelligence by enterprises affects the level of unemployment. The research area specified includes the countries of the European Union (current as of January 12, 2023). This relationship was investigated based on three types of data presented in Figure 1.

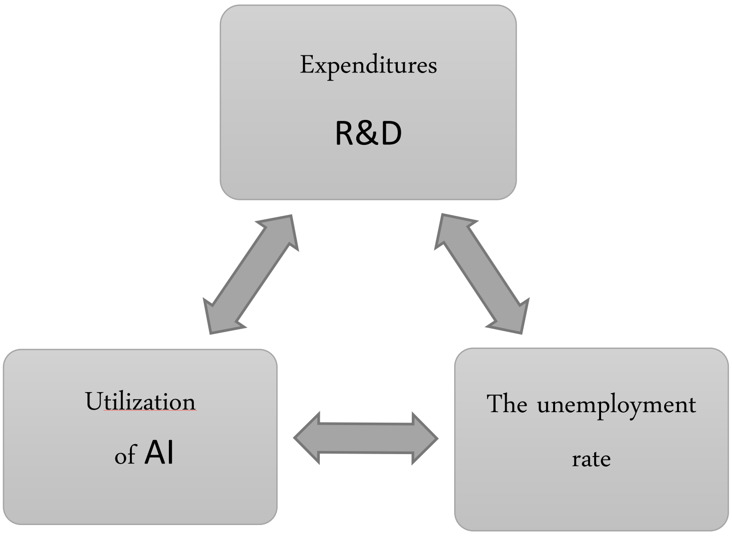

Figure 1. Data used in the study.
Source: Own study.

As shown in Figure 1, the study took into account the level of AI technology usage, the unemployment rate, and the expenditure on research and development (R&D) in individual EU countries. The first two variables directly relate to the study's objective. R&D expenditure data were included to better describe the technological reality of the countries and to deepen the analysis. Three research questions were posed:

RQ1: Is there a statistically significant relationship between R&D expenditure and the unemployment rate?

RQ2: Is there a statistically significant relationship between R&D expenditure and the level of AI technology usage?

RQ3: Is there a relationship between the use of AI technology by enterprises and the unemployment rate?

Document analysis was chosen as the research method. Statistical data available on the Eurostat website www.ec.europa.eu were used, covering: the percentage of enterprises with more than 10 employees using AI technology for 2021, excluding the financial sector (Eurostat, 2022a), the unemployment rate for 2021 (Eurostat, 2022b), national R&D expenditure GERD for 2021 (Eurostat, 2022c), business enterprise R&D expenditure BERD for 2021 (Eurostat, 2022d), and the employment expectation index EEI for November 2022 (Eurostat, 2022e).

For the first four sources (Eurostat, 2022a, 2022b, 2022c, 2022d), data analysis in percentage format was decided upon. The first two sources presented percentage data. Therefore, the GERD and BERD data, which were initially in millions of EUR, were modified. It was decided to adopt the percentage change in expenditure between 2020 and 2021 and between 2012 and 2021, using the expenditure levels from the previous year (respectively: 2012 and 2020) as the baseline for calculating the change. This modification was necessary because currency-form data can be influenced by many additional variables, such as the size of the country. The EEI index, due to the specific way Eurostat calculates it, was left unchanged.

Data obtained from the aforementioned sources were prepared for analysis by standardizing the units and compiled in Table 2.

Table 2.
Data analyzed

Country	UR (%)	UR change 2021-2020 (%)	Companies using AI (%)	GERD: 2021-2020 (%)	GERD: 2021-2012 (%)	BERD: 2021-2020 (%)	BERD: 2021-2012 (%)	EEI
BE	6,3	0,5	10,3	4,71	83,35	6,81	97,97	98,1
BG	5,3	-0,8	3,3	4,9	116,46	2,30	135,43	112,4
CZ	2,8	0,2	4,5	10,96	65,28	14,29	96,42	99,6
DK	5,1	-0,5	23,9	2,33	24,78	3,24	18,26	94,0
GE	3,6	-0,1	10,6	5,88	42,65	5,85	39,78	104,6
EE	6,2	-0,7	2,8	14,57	44,73	16,41	40,48	94,4
IE	6,2	0,3	7,9	-2,04	64,66	5,81	82,91	95,6
EL	14,7	-2,9	4,2	5,65	97,01	8,29	171,52	109,6
ES	14,8	-0,7	7,7	9,39	28,81	10,60	36,68	104,7
FR	7,9	-0,1	6,7	3,92	18,91	3,25	20,77	108,2
HR	7,6	0,1	8,7	15,73	119,73	12,46	123,01	110,9
IT	9,5	0,2	6,2	5,95	29,34	5,25	46,56	108,2
CY	7,5	-0,1	2,6	12,58	143,78	19,09	598,47	103,1
LV	7,6	-0,5	3,7	11,51	58,48	18,27	130,23	98,0
LT	7,1	-1,4	4,5	7,62	108,59	9,48	279,91	99,8
LU	5,3	-1,5	13,0	7,48	31,71	-2,78	10,50	ND
HU	4,1	0	3,0	15,24	101,31	13,74	131,46	100,5
MT	3,4	-1	10,2	10,19	60,36	9,55	75,35	98,3
NL	4,2	-0,7	13,1	4,44	54,37	5,83	84,13	108,2
AT	6,2	0,2	8,8	6,17	39,45	6,17	37,71	103,8
PL	3,4	0,2	2,9	13,16	140,62	13,62	307,93	93,8
PT	6,6	-0,4	17,3	10,16	53,65	14,52	83,06	111,8
RO	5,6	-0,5	1,4	11,22	77,15	13,93	174,77	108,5
SI	4,8	-0,2	11,7	10,87	20,33	11,02	16,63	111,1
SK	6,8	0,1	5,2	9,47	56,92	13,44	112,69	109,0
FI	7,7	0	15,8	8,05	9,65	10,95	9,75	98,5
SE	8,8	0,3	9,9	7,54	29,82	6,85	37,67	103,6

Source: Own study.

The abbreviations of country names in Table 2 are listed in the order of their appearance in Eurostat reports. The individual abbreviations in the column names respectively denote: UR – unemployment rate in 2021, UR Change: 2021-2020 – change in the unemployment rate between 2021 and 2020, GERD: 2021-2020 – percentage change in national GERD expenditure between 2021 and 2020, GERD: 2021-2012 – percentage change in national GERD expenditure between 2021 and 2012, BERD: 2021-2020 – change in business sector BERD expenditure between 2021 and 2020, BERD: 2021-2012 – change in business sector BERD expenditure between 2021 and 2012, EEI – employment expectations index for managers.

Calculations were performed using Excel and Statistica. Data were considered statistically significant for $p > 0.05$.

4. Research Results

To determine the level of unemployment, the unemployment rate for 2021 (UR), the change in the unemployment rate compared to 2020 (UR Change: 2021-2020), and the employment expectations index for managers (EEI) were used. In the area of R&D expenditure, the change in national GERD expenditure between 2021 and 2020 (GERD: 2021-2020) and between 2021 and 2012 (GERD: 2021-2012), as well as the change in business sector BERD expenditure between 2021 and 2020 (BERD: 2021-2020) and between 2021 and 2012 (BERD: 2021-2012), were analyzed.

To answer the research questions posed, the relationship between R&D expenditure and the unemployment rate, between R&D expenditure and the level of AI technology usage, and the relationship between the use of AI by enterprises and the unemployment rate (as per Figure 1) were examined. Spearman's rank correlation was used. Spearman's R and p values are presented in Table 3.

Table 3.
Spearman's R for individual variables

Variables	R Spearmana	p
GERD: 2021-2020 vs. UR	-0,122231	0,543612
GERD: 2021-2012 vs. UR	-0,213904	0,284014
BERD: 2021-2020 vs. UR	-0,009473	0,962597
BERD: 2021-2012 vs. UR	-0,069977	0,728718
GERD: 2021-2020 vs. UR Change 2021-2020	0,011950	0,952825
GERD: 2021-2012 vs. UR Change 2021-2020	-0,005209	0,979427
BERD: 2021-2020 vs. UR Change 2021-2020	0,070477	0,726852
BERD: 2021-2012 vs. UR Change 2021-2020	-0,039835	0,843615
GERD: 2021-2020 vs. EEI	-0,053028	0,796969
GERD: 2021-2012 vs. EEI	-0,034554	0,866919
BERD: 2021-2020 vs. EEI	-0,111187	0,588684
BERD: 2021-2012 vs. EEI	0,044133	0,830492
GERD: 2021-2020 vs. enterprises using AI	-0,473515	0,012602
GERD: 2021-2012 vs. enterprises using AI	-0,603572	0,000859
BERD: 2021-2020 vs. enterprises using AI	-0,464051	0,014758
BERD: 2021-2012 vs. enterprises using AI	-0,710426	0,000033
Enterprises using AI vs. UR	-0,067237	0,738968
Enterprises using AI vs. UR Change 2021-2020	0,037236	0,853706
Enterprises using AI vs. EEI	0,071856	0,727218

Source: Own study.

The first part of the table refers to research question P1: Is there a statistically significant relationship between R&D expenditure and the unemployment rate? As shown, the analysis did not reveal any significant correlations between these two variables. It is important to consider the multitude of factors affecting the unemployment rate, such as social, political, and economic changes in a given area, pandemic-related restrictions, access to natural resources, and so on.

Question P2 concerned the relationship between R&D expenditure and the level of AI technology usage (the second part of the table). The analysis showed a statistically significant relationship between all types of expenditures (GERD: 2021-2020, GERD: 2021-2012, BERD: 2021-2020, BERD: 2021-2012) and the percentage of enterprises using AI. However, it is surprising that the correlation is negative, meaning that as investment expenditures increase, the percentage of firms using AI technology decreases. It should be noted that the presented data on R&D expenditures refer to general national (GERD) or business sector (BERD) investments in research and development. They do not specifically pertain to investments in AI technology development. Higher expenditures might be allocated to research dedicated to other types of technology used by enterprises that do not utilize AI.

Finally, the main research question P3 was analyzed: Is there a relationship between the use of AI technology by enterprises and the unemployment rate? The study did not find any statistically significant relationships between the percentage of enterprises using AI and the variables adopted to determine the level of unemployment: the unemployment rate for 2021, the change in this rate between 2020 and 2021, and the EEI index, which indicates managers' employment expectations. In other words, there is no evidence of an increase in technological unemployment caused by increased use of artificial intelligence. Thus, the study results do not confirm the analyses by F. Bordot (2022) and D. Bailey (2022), which suggest that AI technology contributes to higher unemployment. At the same time, the analyses presented in this article do not confirm the results described by G. Kohli (2020) and C. Lu and Chia-Hui Lu (2022). At this point, the presented results are closer to the research published by G. Anakpo and U. Kollamparambil (2022), who, due to the lack of observed negative impact, recommend further investments in robotics.

5. Summary

According to estimates by Markets and Markets (2022, p. 7), the AI market is expected to grow at an annual rate of 38-40% from 2021 to 2026, reaching a value of $300-310 billion in 2026 (value in 2021: $55-60 billion). This represents a tremendous growth opportunity for AI solution providers. The projected growth in the BFSI sector is $550-560 million, in telecom & IT $490-500 million, in retail and e-commerce $470-480 million, in healthcare and life sciences $460-470 million, in the automotive and transportation sector $270-282 million, in government and defense $280-300 million, and in manufacturing $240-254 million. The question of the relationship between the use of AI technology and the level of technological unemployment is therefore extremely relevant and important for both science and enterprises and their employees.

The presented study did not show a statistically significant correlation between R&D expenditures of individual EU countries and their unemployment rates. However, it confirmed an inversely proportional relationship between R&D expenditures and the level of AI technology usage. No link was found between AI exposure and employment decline in EU countries. It is important to note that there are many determinants of unemployment. These include not only the level of technological development but also the legal regulations adopted in a given administrative unit, its size, natural resource deposits, the education level of the population, and social changes. The study considered data from 2021, a period during which the clear impact of the COVID-19 pandemic on the economic indicators of individual countries could be observed. Therefore, further research is needed to determine the degree of human labor replacement by AI technologies. It is also worth comparing the relationship between AI usage levels and unemployment rates in countries from other geographic areas, particularly in countries where AI usage is high, such as New Zealand, Hong Kong, China, and the USA (HAI, 2022, p. 143).

Above all, it is imperative to closely monitor the level of interaction between artificial intelligence and humans, heeding the words of physicist S. Hawking: "Artificial intelligence is shaping the future of humanity across nearly every industry. It is already the main driver of emerging technologies like big data, robotics, and IoT, and it will continue to act as a technological innovator for the foreseeable future" (Thomas, 2022).

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THE LATEST TRENDS IN PACKAGING DESIGN

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Purpose: Packaging is an indispensable and top-rated component of product that accompanies everyone's life. Its number and widespread use make it easier for consumers in many situations, but it also poses many risks, mainly to the environment. This study aimed to identify the latest research directions in the packaging design field. A review of the literature in this field can give an idea of the research work undertaken in this area of science.
Design/methodology/approach: The study's objective was to use the systematic literature review method and the PRISMA procedure. Research papers from the Web of Science database were reviewed. At the first stage of the study, 46 scientific articles that dealt with packaging design were accepted for analysis in the final step of the procedure.
Findings: The analysis identified four main lines of research in the most current global literature. These were: (1) enhancing product appeal and consumer impact, (2) eco-friendly materials and sustainable packaging, (3) durability and physical protection of product quality, and (4) impact on healthy eating habits and countering food waste. The most popular direction proved to be enhancing product appeal and consumer impact. Papers on this theme accounted for 41% of the publications in the review. A more in-depth analysis indicated that the following research areas emerged within this direction: increasing consumer purchase intent, improving product appeal and image, attracting consumer attention, the impact of packaging elements on consumer perception, and the application of design methods using artificial intelligence.
Originality/value: The research makes it possible to identify the most up-to-date science in packaging design. They provide an opportunity to learn about and reflect on the global situation in this field. The data obtained made it possible to determine that the dominant research trend is marketing, and most research on packaging design is focused on this topic. In the current climate crisis and the widespread call for sustainable action in every field, it is apparent that the latest issues in packaging design do not reflect this trend. Moreover, there is no doubt that packaging is such a standard product that it has a robust environmental impact. However, the directions of scientific work can be influenced, for example, through grant systems.
Keywords: Packaging design, packaging, marketing, environmental protection, SLR.
Category of the paper: Literature review, research paper.

1. Introduction

Due to their numerous advantages, product packaging is becoming increasingly common and indispensable in community life. Thanks to their daily use and the development of their functionality, they fulfil many of the tasks that are set before them (Weinrich et al., 2023). However, braces for progress in this area must take into account the requirements that are placed on packaging. Particularly those resulting from new regulatory conditions such as the New Green Deal. Although this regulation only has an impact within the European Union, the need for sustainable packaging is certainly being observed worldwide.

Another strongly noticeable trend is increasingly diverse and independent consumer behaviour (Min, 2023). These manifest themselves in new needs and expectations on their part. Today's packaging design must also, convey emotional information, provide experiences and meet personalised requirements.

Observation and analysis of current trends in the development of new products leads us to adopt the aim of this thesis as identifying the latest research directions in packaging design.

2. Literature review

According to the European Plastics Converters guidelines, the main functions of packaging include (EPC, 2024):

- Transport.
- Protection and conservation of the environment and of the packed good.
- To minimise environmental impact, packaging design needs to be optimized.
- Reduce waste/spillage.
- Hygiene.
- Help and inform the user.
- Convenience/ergonomy.
- Attract.

Undoubtedly, all of these functions will be under intense pressure from environmental demands, which may prove to be dominant in some areas of the world. According to reports from the World Packaging Organisation, the packaging industry is in constant transformation, driven by the forces of sustainability, technological advances, and consumer demand for innovation (WPO, 2024). In addition to the aforementioned environmental aspects, market issues also seem to be extremely important. Related to consumer perceptions of packaging and persuading them to buy. This is particularly influenced by the highly competitive and self-service economy, in which product packaging is the medium between the consumer and the producer of a good (Pleyers, 2023). Usefulness, Understandability, and Reliability in primary products are becoming increasingly important in the market (Kozik et al., 2024). Besides, in the food industry, packaging colour, material and font are important to consumers (El Oraiby, Kiygi-Calli, 2023). In non-food products, on the other hand, safety of use is important (Bielak, Marcinkowska, 2022). Understanding consumers' differing preferences for packaging and products and their features is therefore crucial for those responsible for packaging design (Wang et al., 2022).

In conclusion, the main determinants influencing packaging design and development will be the growing needs and demands of consumers. In addition, it will also be very important to identify hitherto unrecognised needs. That is, those that are not being met. So such activities may prove to be extremely beneficial and profitable for companies.

3. Methodology

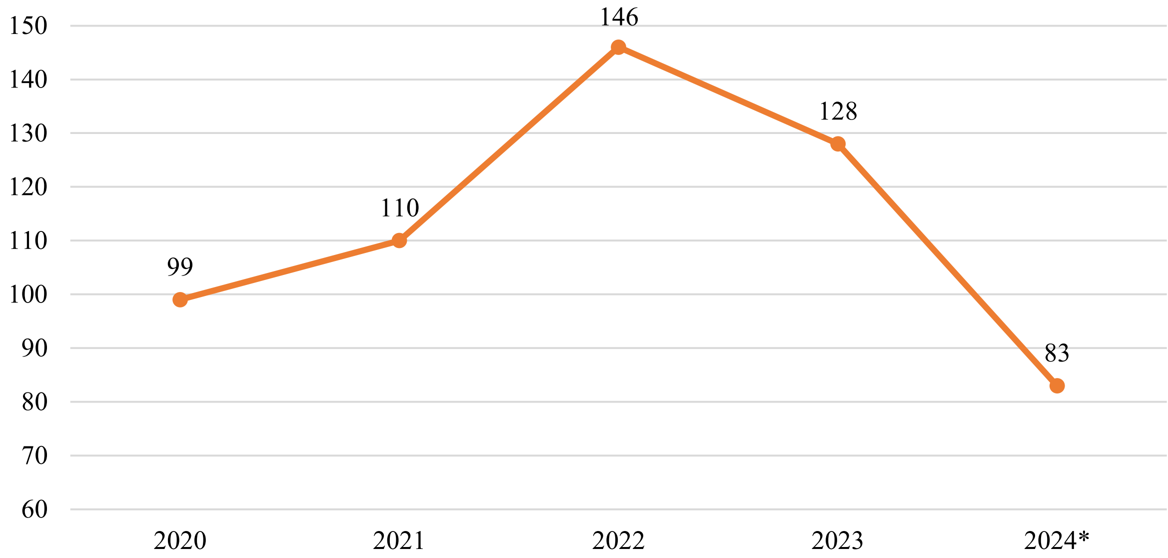
A systematic literature review methodology was used to achieve the stated aim of the study. This method is well-defined in science and is based on clear and rigorous criteria (Thome et al., 2016). A systematic literature review is frequently used in the social and psychological sciences (Fahimnia et al., 2015). As the main research question for this thesis, we adopted:

RQ1: What are the latest research directions in packaging design?

This designation of the research area should be considered new. The Web of Science database, recognized as one of the most relevant and reputable sources of peer-reviewed research (Fargnoli & Lombardi, 2020; Malapane et al., 2022), was used to search for articles. The selected keyword was the term ‘packaging design.’ A search procedure for titles, keywords, and abstracts was used. This defined and planned procedure allowed the search to be broad enough not to limit the number of studies and, at the same time, sufficiently detailed. The study was limited to articles in English, as this is defined as the international language of science, mainly due to the most prestigious international journals that allow publication only in this language. While analyzing and selecting the titles collected, the publications and their abstracts were reviewed according to the systematic literature review procedure by a single reviewer in the person of the author of this publication. The methodology resulting from the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) procedure was used to review the articles (Page et al., 2021).

4. Results

The implementation of the study began with a quantitative analysis of scientific articles. This data was obtained by searching for the phrase 'packaging design' in the Web of Science database. The data obtained are presented in Fig. 1. They show the number of scientific articles in which the search terms appeared in the title, keywords or abstract.



Explanation: *- data up to September this year.

Figure 1. Number of articles on 'packaging design' in the Web of Science database.

Source: own research.

As can be seen in the figure presented, the largest number of articles on the topic under study was published in 2022. However, it is worth noting that the 2024 data was not complete. The material presented confirms that packaging design issues are very often addressed by researchers and there are many of them. Due to the considerable amount of research papers identified, the review was limited only to the most recent research results that appeared in 2024. Therefore, only these papers were included for further steps. This was also directly related to the aim of the study, which was to analyse only the most recent research in the field of packaging design.

In a further step of the adopted procedure, after extracting 83 publications from 2024, further verifications were carried out in accordance with PRISMA. A diagram of this process and its results are presented in Figure 2.

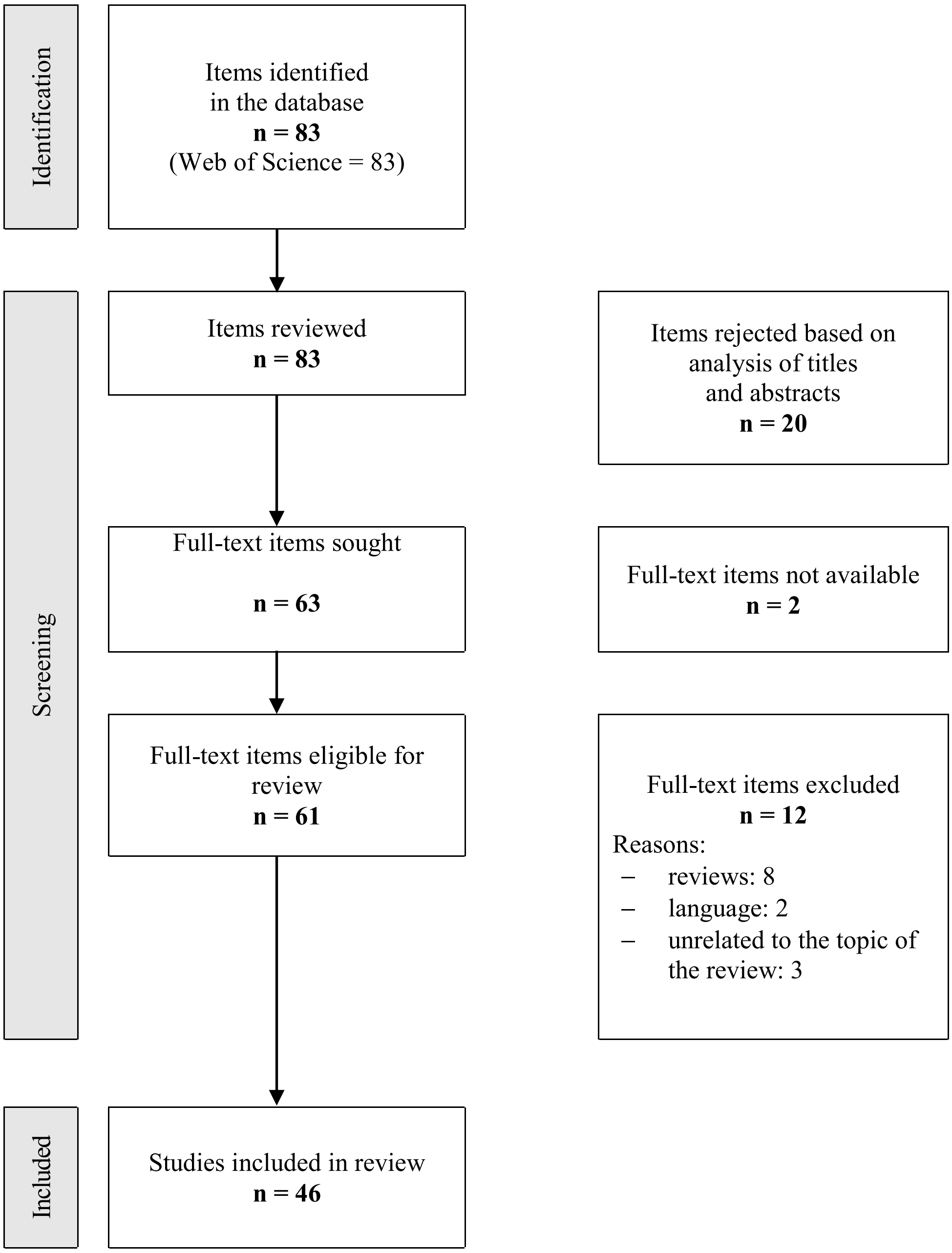


Figure 2. Diagram PRISMA.

Source: own research.

In the first step of the procedure, 83 items containing the searched keywords were obtained. These publications constituted the input den for the analysis. After an initial assessment of the titles and abstracts, 63 items were left that met the objectives of the review. These publications were subjected to further review. For reasons such as the unavailability of the full text or publications not in English, the number of items was reduced. In the final phase of the PRISMA procedure, 46 scientific articles were obtained, which served as input material for the purpose of the study. These publications constituted the main research material in the relevant part of the literature analysis covered in this thesis.

Based on the material that was selected for the purpose, open coding was used and each publication was assigned broader categories, which were then progressively compared and benchmarked. As a result of this analysis, four directions for the most up-to-date research in packaging design were obtained and proposed. The quantitative results of this exercise are presented in Figure 2.

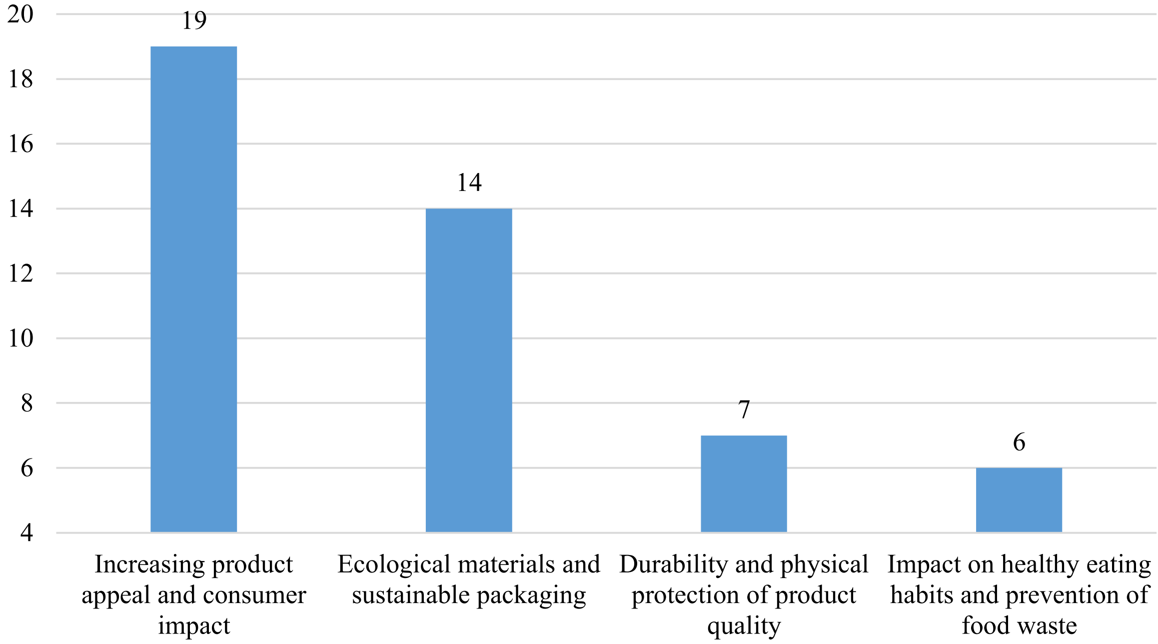


Figure 3. Number of papers on 'packaging design' in the Web of Science database.

Source: own research.

Figure 3 presents the results of the analysis of recent scientific research on packaging design. In the course of the literature review, the collected items were assigned to thematic groups that correspond to trends in science. As can be seen, to the greatest extent current research focuses on: enhancing product appeal and consumer impact (41%). Most likely, this state of affairs corresponds to market and scientific demand for this type of study. In second place, the most popular studies concerned ecological materials and sustainable packaging (30%). To a decidedly lesser extent, studies dealt with: durability and physical protection of the product quality (16%) and impact on healthy eating habits and prevention of food waste (13%).

In order to characterise the most popular research direction in more detail, an in-depth assessment was made of the research papers that were assigned to the thematic group: enhancing product appeal and consumer impact. The qualitative analysis carried out made it possible to identify the following research areas. These are presented in Figure 4.

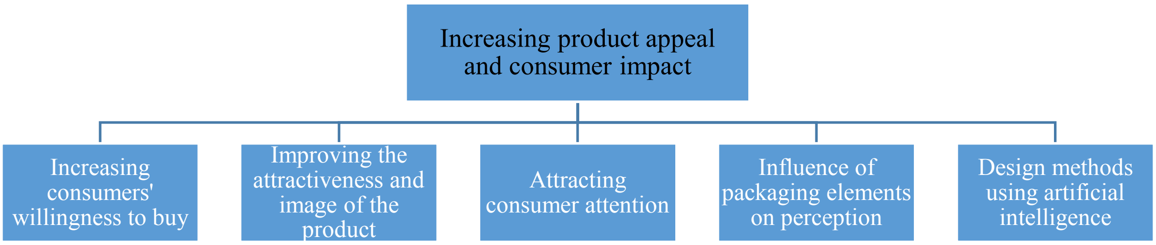


Figure 4. Research areas related to packaging design are assigned to enhance product appeal and consumer impact.

Source: own research.

A word cloud of publication abstracts (fig. 5) was created to visualise the most common themes and threads taken up within the identified and defined direction of packaging design research which was to enhance product appeal and consumer impact. This visualisation provides a quick overview of the key problems and issues that were addressed in this work (Kalmukov, 2021).

Explanation: The words 'design' and 'packaging' were removed from the cloud, and the words' consumer' and' product' were aligned.

Figure 5. Word cloud created from abstracts of scientific papers attributed to studies grouped under enhancing product appeal and consumer impact.

Source: own research.

As can be seen in the presented Figure 5. to the greatest extent, the themes of the specific direction concerned products and consumers. That is, the main elements that marketing is concerned with. It is also worth noting that a large part of the research was about food, as evidenced by the large size of the word.

5. Summary

The study carried out achieved its objective and provided an answer to the research question posed. As a result, the most popular research direction related to packaging design in 2024 was identified as enhancing product appeal and consumer impact. More in-depth analyses identified four areas of research within this direction. These activities provided an opportunity to conclude that the current mainstream research focus is currently on packaging marketing. Only in second place in terms of the number of studies was a direction identified that was given the name: green materials and sustainable packaging.

The results obtained may come as a surprise, given the much-publicised discussions about the climate crisis in many forums. As can be seen from this example, the scientific world and researchers have taken as their main focus of packaging-related research topics topics with a marketing background. That is, they have mainly oriented their research towards consumers and products. The aim of this research has generally been to increase consumers' willingness to buy, to improve the attractiveness and image of the product, to attract consumer attention. And also research into the influence of packaging elements on perception and the application of design methods from the field of artificial intelligence. These topics empirically confirm that product packaging is treated by science mainly as a marketing tool.

The limitations of this work include the relatively short period from which the research was selected. In contrast, an attempt to analyse publications from several years could exceed the quantitative limitations of this publication.

It remains to be believed that socially important topics such as environmental issues, food health or food waste will become mainstream and research directions in the coming years. Certainly, packaging as common products and frequent tools with multiple functions can be used to achieve these aforementioned goals as well. And the effects and impacts of their implementation can bring more collective benefits to society. Influence on research directions can be achieved through the creation of dedicated grant schemes.

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ARTIFICIAL INTELLIGENCE IN PROJECTS MANAGEMENT

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Purpose: The article reviews the use and influence of artificial intelligence (AI) on projects management and resultant benefits. The effects of AI technology on the methods and tools of projects management were analysed. The AI challenges in projects management practice were tested.
Design/methodology/approach: Exploration of sources was carried out using the Desk Research method which belongs to the group of qualitative research methods and consists of analysis of existing materials such as documents, WWW pages and other archival sources.
Findings: During the works the areas of applications were analysed with challenges of using the AI in projects management. Besides, the use of selected tools based on artificial intelligence were suggested.
Originality/value: Identification of the areas using artificial intelligence in projects management and the resultant benefits, as well as the specification of challenges related to the AI in projects management and proposals to use the selected tools based on AI are the basic values of this article. It's addressed to those interested in modern project management methods.
Keywords: artificial intelligence, projects management, software based on artificial intelligence, virtual assistant.

1. Introduction

The projects management plays a crucial part in the functioning of modern enterprises and organisations. However, with the fast development of technology the traditional methods of projects management gradually revealed some flaws, such as a low efficiency and slow response. The artificial intelligence (AI) as a leader of the present technological development profoundly changes the way of activities of all branches, and the projects management is not an exception here (Wachnik, 2022).

According to the definition, the "artificial intelligence is the systems' ability to interpret the data from external sources" (Pałka, 2023). AI refers to the technology which enables the

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computer systems to indicate human skills such as reasoning, learning, planning and creativity (Bento, Pereira, Gonalves et al., 2022).

Since the XXI century, with large data sets and processing in the cloud, the AI initiated a vehement increase and made great achievements in diagnosis of the picture, processing of the natural language, intelligent recommendations and so forth (Datta, Islam, Sobuz et al., 2024).

The artificial intelligence technology largely influenced the projects management. First, it may assure a much more accurate and faster data analysis and predictability, thereby assuring a more reliable support in the project decisions. Second, the AI technology may automate various aspects of project management, such as allocation of tasks, monitoring of progresses, identification of the risk, estimation and forecasting of costs etc. Such operations improve effectiveness and increase the project management precision.

Admittedly, owing to intelligent cooperation tools and platforms the AI technology facilitates the communication and cooperation between the teams, simultaneously enabling the work of inter-regional and intercultural project teams.

Importantly, the use of the AI technology may largely facilitate the project managers their coping with uncertainty and changes, thereby improving the project's adaptation and flexibility and increasing its chance for success and competitiveness (Bento, Pereira, Gonalves et al., 2022).

Gartner's studies indicate that till the year 2030 as many as 80% of the tasks connected with the project management will be carried out by artificial intelligence supported by large data sets, machine learning (ML) and processing of the natural language (Nieto-Rodriguez, Viana Vargas, 2023).

AI may analyse fast the large amounts of data from the market and supply the information about the trends and preferences of those clients whom we want to contact. Using the collected information the organisation may adjust its long-term strategy to current market requirements and forecast the future changes, which increases the chance of success around the large competition.

Included into artificial intelligence are the component elements shown in Table 1.

Table 1.
Components of artificial intelligence

Component	Characteristics of the component
Machine teaching	The AI branch where the programs and systems automatically modify their knowledge and procedures with the aim to improve the output; the machines follow the distinct instructions of the person who introduces the data, and before the task the device gets a lot of trial examples; due to education and analysis of the designs the artificial intelligence achieves the purpose posed by the person; this scope includes also the deep learning posed by the person; this scope includes also the deep learning – both supervised and non-supervised;
Natural Language Processing (NLP)	enables the computers to understand the human language and create it (creation of words or independent creation of new sentences by the machine) and manipulate it; NLP processes the input data containing the natural text and voice; it is used in the present virtual assistants (Siri, Alexa, Cortana) and in the written language and speech for all languages available for the program;

Expert systems	This is a collection of computer programs using the bases of knowledge and collected rules to solve the decision problems; the expert system reflects the processes of decision making by the human being specialised in a given domain; it has three characteristic features: knowledge bases, procedures and ability to extend the knowledge;
Processing of the picture	This is the area which is focussed on enabling the computers to identify and understand the data of the persons and objects according to the provided video pictures and films; in this case the processing of illustration allows to reply both to the human way of outlook and recognition;
Processing of speech	This scope includes the processing of speech into a text and vice versa; this technology allows to interpret the human speech while being an alternative for human interactions or for transcription purposes; the greatest use of this AI branch presently occurs in servicing a client in the vocal prediction systems;
Robotics	Artificial intelligence plays a key role in robotics in the context of designing, construction and programming of the robots; Robotics use many various technologies to form the systems which are able to program the physical tasks; AI enables the robots to process the sensory information, to learn, to take decisions and interactions with the environment.

Source: Own work based on: European Commission, 2019.

New types of AI appeared recently, including among others the generative artificial intelligence (Gen.AI). This is the type of AI earmarked for creating or producing of the new contents – for example pictures, music or a text - using specific algorithms and models based on self-education. The Gen.AI success depends on the degree of fulfilling the existing challenges within the data management, using such tools as DataOps[1], MLOps[2] (Patience, Bartley, Curtis et al., 2024).

Going into details of this subject the Author hopes to deliver valuable observations and practical guidelines for project managers to better cope with the possibilities and challenges of the AI age.

2. The use of artificial intelligence in projects management

2.1. Scheduling and planning of project works

Traditional planning of projects is usually based on experts' experience and historical data which are easily affected by various subjective factors and restrictions, which results in inaccurate or too conservative planning. The AI technology assures more precise and intelligent planning and scheduling of projects through a detailed analysis of a great deal of data and simulation algorithms. The planning tools based on artificial intelligence may identify fast the critical paths and points of risk in the project, optimize allocation of resources and scheduling of tasks, and improve efficiency and quality of the project accomplishment. Furthermore,

[1] It is a connection of DevOps and Data Science, which means that it is focussed on the process of fast delivery of data to application with a simultaneous improvement of their quality. DataOps is the use of more agile practices of data management with the aim to support the business results based on the data, simultaneously allowing to optimise the operations on the data.

[2] This is a connection of DevOps and machine learning. It focusses more than DevOps on the data and machine learning.

the AI technology may provide dynamic adjustments based on the data acquired at the actual time and advancement of the project realization aimed at the monitoring and forecasting of the project's progresses and costs at the actual time. AI helps the project managers to identify the problems and take activities at the right time so as to achieve better the project goals. Gen.AI may be used to simplify the exploration of historical data to help in the general planning and optimisation of the project. Emphasized should be the fact that the Gen.AI technology may be also used to generate a complex project documentation.

It is worth to pay attention to the project management tool called the Forecast. It uses the algorithms of machine teaching to forecast the time needed to finish the project. According to the historical data and valid indices of the project it is possible to generate the forecast related to the schedule and resources. This instrument helps the project teams in better planning and management of their work.

2.2. Estimation and prediction of costs

Using the AI in estimation and prediction of costs assures a higher accuracy and reliability in projects management. The traditional estimation of costs is usually based on the historical data and experts' evaluations which are easily affected by subjective factors and errors and this causes inaccurate estimation of costs. For their more precise estimation the artificial intelligence technology may discover some concealed correlations from mass data through a precise analysis of large data sets and algorithms of machine teaching (Głowasz, 2022). For instance the costs prediction models based on artificial intelligence may use historical project data and information about the costs at the actual time. Combined with complex algorithms to form forecasts they can estimate more precisely the costs of the project and help the project managers to take rational decisions. Gen.AI may be used to support the costs estimation, analysis of costs and benefits, to carry out an analysis of the worked out value and to identify some mitigating activities when the costs are exceeded.

The implementation of AI may be sometimes connected with high costs which depend on many factors. The organisations should calculate the costs of the purchase, implementation and training of employees and maintenance of the tools and systems based on the AI. Furthermore, it is worth to consider the technical and human resources to use the purchased systems effectively.

2.3. Management of the risk and support in decision-making

One of the most developed areas of the project management automation is the risk management. The machine teaching algorithms using the collected data about earlier projects are able to predict the potential risk and suggest possible effective activities excluding them, which allows for the current adjustment of the project to the changing conditions.

The algorithms contained in AI may analyse the data from various sources and using the expert systems they may help the project leaders to take the most accurate decisions. Such operations refer to every stage of the project work.

The use of the AI in the risk management and decision support assures a more comprehensive and effective solution for the projects management (Głowasz, 2022). The traditional management of the risk is often based on experts' experience and static models of risk evaluation, which hinders the comprehensive identification and response to the potential risk in the project. On the other hand the AI technology may carry out the analysis of large sets of data and use the algorithms of machine education to get out potential correlations and regularity of the risk factors from huge amounts of data in order to achieve a more precise and comprehensive identification and evaluation of risk. For example the risk management system based on artificial intelligence may dynamically monitor and analyse different risk factors in the project, predict possible risky events and help the project managers to formulate on time the precautionary measures to decrease the effects of risk on the project.

AI may analyse huge amounts of data from the market and deliver the information about the trends and preferences of the clients which we want to contact. Using the collected information the organisation may adjust its long-term strategy to the market's current needs and forecast the future changes, which increases the chance of success around a high competition.

2.4. Communication and cooperation in the project

The use of AI in communication and cooperation assures a more efficient and convenient way of work for the project teams. In the traditional project management the communication among the members of the team is often based on traditional methods, such as meetings and e-mails, which is connected with such problems as a low efficiency of communication and untimely transmission of information. The AI technology may assure communication and cooperation among the members of the team at the actual time, owing to intelligent tools and platforms for cooperation (Meharwade, Dsouza, Gupta et al., 2024; Wang, 2023). For example to improve the team's efficiency and synergy, the team cooperation platforms based on artificial intelligence may provide a live chat and documents online, assign the tasks and other functions which facilitate the team members a fast communication and cooperation at any place and time.

To use the AI virtues completely, the managers must develop some supplementary skills. They must redefine their role as the leaders in the organisation and focus on social and relational dimension of their work. Therefore, the managers should find new ways of holding the teams' leadership and management. Technical skills, emotional intelligence as well as the abilities of communication and listening become essential for managers. These skills are particularly important for the teams management in a very respectable, humanitarian and ethical manner, despite the increasing impact of the AI technology on the work environment (Wirtz, Weyerer, Geyer, 2019).

A new role in the projects management is that of the virtual assistants. The digital assistant learns according to earlier entries, data from the project design and general context to adjust the interactions and intelligently intercept the critical information about the project. Such assistant assures immediate revisions of the project status and helps the project manager to update the time and progress of the tasks through the text, voice or chat. Specialists of the projects may use a virtual assistant acting according to Gen. AI to supplement their own analyses or obtain the first working versions to be surveyed by experts. Examples of using a digital assistant include preparing the first version of the analysis of costs and benefits, carrying out a data analysis to be used in recommendation of a change of the scope, preparing a schedule and carrying out the risk analysis. The final result will (probably) require a moderate intervention on the part of an experienced professional to make sure that it is complete and precise (Pałka, 2023).

2.5. Management of quality and monitoring of quality

The use of AI in the management and monitoring of quality assures a more refined and automated tool for the quality management in projects. The artificial intelligence provides assistance in personalisation of project solutions considering individual needs and requirements of the principals. Such an approach translates into a higher satisfaction of the final customer and stakeholders owing to the provision of the higher quality solution.

Traditional management of quality is usually based on manual sampling and control, which is susceptible to the influence of human factors and a subjective evaluation and this results in omission of the data or incorrect evaluation of their quality. The AI technology may assure monitoring and forecasting of the quality of projects at the real time by intelligent tools and algorithms of the quality management. For example, while analysing a large amount of the project data and quality indicators, the quality management system may identify fast any possible problems and irregularities connected with the quality and also remind the project managers to start acting on time to dissolve them.

There are many tools based on the AI now which verify and improve the contents of the project documents, eliminating errors and inaccuracies and thereby improving the quality of the project documentation. Such use considerably confines the risk of defects in consecutive stages of the plan due to incorrect project documentation.

Artificial intelligence assures assistance in personalisation of the project solutions considering the principals' individual needs and requirements. Such an approach contributes to the final client's higher satisfaction resulting from supplying the product or service of a higher quality - which meets better the stakeholders' needs.

2.6. Allocation and optimisation of resources

The use of AI in allocation and optimisation of resources assures more efficient means of the management of resources. According to the collected data the applied algorithms may suggest to the project leaders an optimal (in specified conditions) assignment of resources for the project, which allows to reduce the costs and assure a more effective work of the project team.

The traditional allocation of resources is often based on the experience and the rules, which hinders a complete use of the potential of resources causing a wastage and ineffectiveness. Instead, the AI technology may achieve a dynamic implementation and optimisation of the project resources owing to an effective allocation of resources and algorithms of optimisation. For instance the resources management system based on artificial intelligence may allot and adjust the resources analysing in detail such factors as requirements of the project, the team members' skills and availability of resources in order to maximally fulfil the project requirements and improve the use of the resources.

Jira from Advanced Roadmaps for Jira uses AI in one of the most popular tools for projects management on the market. It enables a more effective allocation of resources in the projects, forecasting the dates of finishing the particular stages of accomplishment, and warns about the potential conflicts.

3. Challenges connected with the use of AI in the project management

The AI technology brings many merits to the projects management but its use is exposed to a number of challenges. The lack of the data is one of the basic challenges connected with the use of the AI in projects management where the project's leader should provide the system with an appropriate amount of the qualitative data for analysis. Many projects have difficulties in this area, which may result in a lower effectiveness of the AI activity and false results.

Table 2.
Challenges in the use of artificial intelligence in projects management

Challenge	Comments
Lack of the data of adequate quality; safety and protection of the data's privacy.	The artificial intelligence training needs a huge amount of the data and the real ones are expensive and more and more difficult to get; therefore the synthetic data are more and more important; these are artificially formed data which replicate the quality and statistical properties of the actual data but they do not contain any real information coming from the real people or the real sources; they are generated through modelling of statistical designs and properties of the data from the real world;
Lack of transparency in the algorithms of artificial intelligence	The lack of transparency in the algorithms action means that the users, decision makers, and the general society do not understand completely the processes of decision making by the AI; there is a need to form some mechanisms which would facilitate the understanding of the general decision process and possible evaluation whether or not the algorithms conform with the society's ethical values; while the artificial intelligence becomes more and more advanced it should enable people to understand how the machine teaching algorithms create the output data.

Cont. table 2.

The users' competences	The users basic competences include the basic knowledge on the AI and its applications, ability to use the AI tools and ability to understand and interpret the results generated by the AI systems; the artificial intelligence extorts a change and increased competences; new categories of IT specialists will be necessary, such as: specialists in machine learning, from python, and those experienced in working with libraries – data science and artificial intelligence.

Source: Own work.

Important challenges are also the problems with the quality of data and protection of privacy. The AI algorithms require a lot of data for their servicing but the quality and integrity of the data may be endangered, while the gathering and using of data may be associated with a decrease of privacy and some legal regulations. Using the AI within the projects management we should pay special attention to the safety and privacy of introduced initial data. Such information should be properly secured against a non-authorized access and possible infringements. Approximately 80% of the time spent on preparation of the ML algorithm is focussed on gathering and cleaning of the data which the algorithm collects while they are raw and not structuralised and transforms them into structuralised data which can train the machine learning model (Nieto-Rodriguez, Viana Vargas, 2023).

Another challenge is also the lack of the transparency of artificial intelligence algorithms. Some AI algorithms act on complex principles which are difficult to understand and explain. This may contribute to limited trust and acceptance of the algorithms' results by the project managers and cause their limited use. According to the complicated algorithms, the systems based on artificial intelligence may undertake specified decisions which are difficult to understand by the employees. Organisations should work out the methods which decode the decisions made by the AI, both to understand the process and to fulfil appropriate regulatory requirements.

The use of the AI poses new requirements and introduces changes for the project managers and teams. The project managers must have an interdisciplinary knowledge and skills so as not only to understand the basic theories and methods of projects management but also to know the principles and use of the AI technology. Furthermore, the project managers must be able to take decisions based on the obtained data. The AI technology may assure a rich support of the data, but the project managers should be able to analyse and use such data so as to get out some valuable information and observations, assuring a scientific basis to take the project decisions. The use of the artificial intelligence will definitely change the traditional style of the project team's work and division of the roles. The members of the team must be flexible to adapt themselves to changes and to learn new skills for close cooperation with the AI technology. It is also important to consider the role played by the person in connection with taking the decision and supervising the projects where a considerable role is played by the algorithm. We can acknowledge that these aspects are connected with the teal management (Laloux, 2015).

The use of the software and instruments based on the AI and the degree of their use raises the issues of ethics and responsibility. Organisations should show more respect to ethical aspects of their use and select those responsible for the consequences of decisions and ways of using.

4. The projects management tools based on artificial intelligence

The development of the software for project management based on the AI became an important trend in the projects management area. The software functions of this type comprise an intelligent support of decisions, automated planning and scheduling as well as the monitoring and forecasting at the actual time. The intelligent function supporting the decisions provides the project managers with scientific bases of the decision making and suggestions through an analysis of large data sets and algorithms of machine teaching.

The function of automated planning and scheduling may – according to the project's requirements and resources - automatically optimise the projects plans and allotments of tasks and also improve the project's fulfilment efficiency. The function of monitoring and expectation will follow the project's progress, costs and quality at the real time by acquisition and analysis of data and expectation of possible problems and undertaking some operations in advance. Such software functions for the project management – based on the AI technology – enable a better adjustment to the complex and uncertain project management. With the continuous development of the AI technology, the project management software based on it will surely be more and more popular and will play a more and more important role in the projects management practice.

Presented below is the software useful in projects management and based on artificial intelligence:

- ChatGPT 4 – worked out by OpenAI; it makes available the API interface for other programs; advanced language model which can give answers, conduct conversations in a natural way and help to edit texts and project descriptions;
- WriteSonic – assists in creation of various contents from blog articles to advertisement contents, offering numerous hints and adaptations to different categories of contents;
- Eightify – abbreviates and sums up the contents of films from YouTube, which is an ideal solution for the fast acquisition of essential information;
- Gist/Claude – creates notes and elaborate summaries from the meetings; it is a useful tool for participants of the meetings;
- Otter AI – prepares the transcription of records and summaries in Microsoft Teams;
- Browse AI – enables the programming of the processor which collects the data from the defined web pages and monitors the changes on those pages;

- TogglTrack – enables the project teams to monitor and control the time devoted to specified tasks; it is used to trace the efficiency, allocation of resources and generation of the reports related to the use of time;
- Simplified – enables the teams' steady cooperation and presentation using the artificial intelligence;
- Compose AI – facilitates answering the emails;
- Eye Contact by NVIDIA – processes fast the picture from the internet camera which creates an impression that the user always looks into the lens instead of the screen of his monitor.

Modern platforms for projects management use more and more AI technology to assure more efficient solutions for project management. Intelligent functions of these platforms include intelligent planning of projects, prediction analysis, intelligent cooperation and automated reporting. The function of intelligent planning of projects uses the AI algorithms and analysis of large sets of data, which enables a fast identification of the critical paths and risk points in the project. The other benefits are the optimized allocation of resources and scheduling of tasks and improvement of efficiency and quality of the project realisation. The predictive analysis function – through the analysis of historical data and information at the real time may predict possible problems and trends in the projects.

5. Summimg up

One of the reasons of a failure to finish the projects successfully is the low level of the maturity of technologies used in the project management (Project Management Institute, 2023, 2024). Such situations may be changed radically owing to implementation of the AI technology. This technology is quite advantageous in projects management considering the increased effectiveness in decision making, optimised allocation of resources and increased possibilities of the risk management. Intelligent platforms and software for the project management provide the project managers with more complex and intelligent tools for management which are helpful in efficient use and successful accomplishment of the projects. Due to the introduced AI technology the project management may achieve automation in planning, completion, and monitoring.

According to 2024 Trends in Data, AI & Analytics, Gen.AI will play a key role in taking a decision based on the data. Gen.AI will be able to help the project managers through automatic generation of visualisation and a hint, thereby simplifying the task of the graphic presentation of analyses. The next area where the Gen.AI may generate benefits is the automated finding of anomalies and analysis of the source reasons. Gen.AI may show extreme values with the causes of their origin; otherwise the non-analysts would not be able to notice them. The next area in which the Gen.AI will have a considerable influence on explanation of the results of analysis is that the text is generated in the natural language understood by laypersons.

Before the artificial intelligence in projects management there are also some sure challenges which should be continually investigated and solved. Such challenges are among other: the quality of data and non-transparent algorithms and users' competences. At the same time the use of AI also imposes some new requirements on project managers and teams which continually have to learn in order to cope with the changes and development within he project management area. We should also take into account the increased supply of electricity in connection with the AI systems.

Summing up, the impact of AI on project management contributes to an improvement of the management effectiveness, optimisation of the decision-making process, and facilitates the team work, which offers high guarantees of the project's success.

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AGILE VALUES IN A MODERN ORGANIZATION

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Purpose: The reason for writing this paper was the growing popularity of the Agile concept in the IT environment. Since the Agile Manifesto, this concept has been used in project methodology as a substitute for Waterfall solutions, of course taking into account the specificity of IT projects.
Design/methodology/approach: This paper focuses on values of the Agile[1] in the context of changes in a modern organization. The basic features (distinguishers) of this concept, such as flexibility, decentralization and adaptability, are presented in this paper. The mentioned features are reflected in innovative solutions of Industry 4.0.
Findings: The work was based on a literature review, and its added value is the presentation of the framework of a new concept of project methodology, which is particularly useful in team work on IT projects.
Practical implications: The presented framework, supported by an analysis of the differences between the traditional Waterfall method and the Agile concept, may be useful for scientific and practical communities, especially in didactics in the education fields of business informatics.
Originality/value: The topic of research on the Agile concept is “fresh”. “Agile Manifesto” or “Manifesto for Agile Software Development” - a declaration of common principles for agile software development methods, was developed at a meeting that took place on February 11-13, 2001 at Snowbird in the USA (Utah). The meeting was attended by representatives (17 people) of new software development methods, which are an alternative to the traditional approach based on the Waterfall.
Keywords: Agile, Waterfall, IT, project management, IT projects, AI.
Category of the paper: General review.

[1] The name of the concept so big letter.

1. Introduction

The steam engine revolutionized physical labour by overcoming previous limitations, driving significant industrial and societal advancements. Similarly, the second machine age—characterized by rapid progress in computing and digital technologies—is transforming cognitive capabilities. These technologies enhance ability to process information and shape the environment, allowing to transcend intellectual boundaries and unlock new opportunities for growth and innovation. In this context, cognitive power is emerging as equally critical to human progress and societal development as physical power once was. Just as the industrial revolution's advances in physical capabilities led to profound progress, the current expansion of cognitive capacities is expected to drive equally significant advancements (Brynjolfsson, McAfee, 2014).

To navigate this new landscape effectively, organizations must adopt methodologies that support flexibility and responsiveness. Agile serves as an umbrella term for various approaches that embody these principles. The concept of Agile" has no universally accepted meaning. Agile is a way of thinking and a set of principles that puts an emphasis on adaptability, teamwork, and ongoing project improvement. It places a strong emphasis on providing clients with value promptly and adjusting to change (Żółkiewicz et al., 2022).

Agile development methodologies gain recognition for their ability to manage time-to-market constraints while accommodating changes throughout the software development life cycle. However, these approaches require adaptation to the specific conditions of various contexts to ensure optimal outcomes. Customizing agile practices enables teams to maximize the benefits of agility while simultaneously aligning with project objectives, thereby facilitating the efficient delivery of high-quality software (Cao et al., 2009).

There was a period when the concept of "agile" had yet to be formally named. It originated from the need to move away from traditional, cumbersome software development methodologies that often-required years to deliver a complete product. The origins of this approach can be traced to the Japanese movement for improving production quality and the pioneering efforts of Toyota. At Toyota, a team of Japanese engineers developed the Toyota Production System (TPS), which is rooted in the principles of complete waste elimination, including Just-in-Time and Autonomation ("automation with human touch") with the tool Kanban (Ohno, 1988).

In 1986, an article titled *The New New Product Development Game* was published in *Harvard Business Review* (Takeuchi, Nonaka, 1986). Although initially limited in popularity, it later inspired the pioneers of the Agile methodology in the United States, who became interested in the practices of leading Japanese companies described in the publication. From that point on, an increasing number of companies in Japan, and later in the United States and the rest of the world, began striving to improve both people and processes (Żółkiewicz et al., 2022).

Several approaches, including Scrum, Extreme Programming (XP), Dynamic Systems Development Method (DSDM), Adaptive Software Development (ASD), Crystal, Feature-Driven Development, and Pragmatic Programming were developed to reduce time-to-market and enhance value delivery to customers in a more efficient manner (Flewelling, 2018). However, there remained a gap that none of the existing methodologies had fully addressed.

The turning point occurred in February 2001, when seventeen individuals from diverse software development communities convened at a ski resort in Utah to discuss how software development could better adapt to the evolving needs of users. The outcome of this summit was not a new framework, but rather the formalization of a set of values and principles, which emphasized the recognition of people as the most critical element in the development process (Flewelling, 2018).

Today, agile is regarded as a continuously evolving philosophy that has given rise to a wide range of frameworks and methodologies, all aimed at improving the dynamics of modern work environments.

The aim of the paper was a presentation of framework of agile based on main features such as flexibility, decentralization and adaptability. The article is structured into five sections: Introduction, Background of analysis, From Waterfall to Agile, From machine to brain in modern organizations, Conclusions and Discussion.

2. Background of analysis

Radical changes in the way organizations operate have been proposed in management, with a focus on customer satisfaction, team collaboration, and continuous improvement. The key is to shift away from traditional management methods, aiming for higher productivity and innovation while ensuring deep job satisfaction. It emphasizes the importance of open communication, working in short, customer-centric cycles, and transparency, creating a work environment that fosters the full realization of human potential and leads to above-average results (Denning, 2010).

To adapt to the dynamics of change, business practitioners and scholars have proposed agile solutions as a contrast to the waterfall approach. Craig Smith described forty variants of the Agile methodology. Moreover, there are more than seventy different Agile practices (Denning, 2010).

The Agile methodology is based on a customer-oriented approach that includes key actions such as adaptation, delivery, and inspection. Agile requires a focus on iterative and incremental change. The iterative approach is suitable when the final product is not fully defined, and the emphasis is on its functionality and usability—on its effect. After each iteration, the product should be functional in some way, with subsequent stages improving it. This process reflects an incremental model, where each stage enhances the product's functionality or quality (Krzystek, 2021).

Unlike the waterfall method, which follows a predictive approach, Agile adopts an adaptive, empirical framework focused on experience (Alsaqqa et al., 2020). The predictive approach is suitable when the desired outcome is well-defined, the process is clear, and the product becomes functional only after all components are integrated at the end of the process. This distinction highlights how Agile methodologies address diverse project needs: iterative development fosters adaptability in environments marked by uncertainty, enabling ongoing refinement as understanding evolves. Incremental development, by contrast, focuses on delivering smaller, functional components over time, making it particularly effective in contexts where delivering value early and iteratively building towards a final product is advantageous (Făgărășan et al., 2021).

3. From Waterfall to Agile

The Agile approach is replacing the Waterfall model due to the development of digital technologies, remote work, and the increasing demand for IT projects (intangible assets) (Gajdzik, Kopeć, 2022). The advancement of digital technologies has been accelerated by the concept of Industry 4.0, which is based on the following technologies: big data, artificial intelligence, cloud computing, Internet of Things (IoT), additive manufacturing (3D printing), autonomous robots, cybersecurity, augmented reality (AR), and simulations and digital twins (Erboz, 2017). Since this concept is strongly promoted in EU countries, there is a need to present the Agile framework.

Table 1.
Agile and Waterfall: comparison analysis in IT projects

Waterfall	**pros**	used in a low-complexity, repetitive environment, such as HR and payroll; used for projects with easy-to-understand requirements; defined results and review process; the method is easy to adapt, even if teams change; the process and results are well documented; easy management
	cons	not effective when unclear requirements; lack of involvement of the customers; uneven loading of the resources; going back to a previous phase to make changes is difficult (difficult “last minute” correction); less time for testing; no time to fix test defects; lot of documentation; schedule and cost overruns; customers is not a member of team project; full financial security for the execution of the project is needed

Cont. table 1.

Agile	**pros**	customer is engaged in the development process all the time; agile method of software development; maintains the quality of development; process is completely based on continuous progress; minimalization uncertainty and mitigation of potential risks by ensuring both the customer and the team have a clear understanding of what is completed and what remains unfinished; budget divided into stages
	cons	limited documentation; fluctuate, flexible project costs; uncertain project end; difficulty in scaling in large, complex projects with multiple teams

Source: own elaboration based on (Rasmusson, 2010; Mokhtar, Khayyat, 2022).

Agile frameworks are not absolute. The application of Agile frameworks alone does not make an organization truly Agile. Some organizations simulate the use of Agile by dividing work into smaller portions while applying a Waterfall approach to each segment. Others limit Agile frameworks to a single department or specific projects, resulting in a hybrid model of Waterfall and Agile, often referred to as „WAgile". For an organization to genuinely identify as Agile, it must undergo a fundamental shift in mindset that permeates the entire organization at the operational level, guided by three core principles (Denning, 2018):

- The Law of Small Teams: while some Agile frameworks, such as Scrum, suggest that a team should consist of 3 to 9 members (Theobald, Schmitt, 2020), the appropriate team size for an organization depends on factors like project scope, organizational scale, and the specific characteristics of the industry or sector;
- The Law of the Customer: in the context of Industry 4.0, this principle is grounded in product customization and personalization to meet individual customer needs (Samita et al., 2024). With the development of the internet and the exchange of information, access to products has transformed, and competition among enterprises has significantly intensified. This shift has led to a departure from mass production in favour of a more individualized approach that considers the needs and preferences of individual customers;
- The Law of Networks – The entire enterprise operates as part of an interactive network, where ideas can emerge from any point within the system, leading to innovative solutions (business networking). Network-based solutions are founded on the principles of decentralization, fostering collaborative competition (coopetition) in business (Sroka et al., 2014). The exchange of information and consumer feedback positions the customer as an integral part of this interactive network.

Based on the aforementioned laws and the analysis presented in the table (Table 1) forms the foundation for identifying three core values that underpin the Agile framework:

- decentralization,
- flexibility,
- adaptability.

These values, discussed in detail in this section, find direct application in modern Industry 4.0 technologies and are crucial characteristics of modern organizations.

Decentralization encompasses various aspects and implications. From a technological perspective, it primarily relies on blockchain technologies and emphasizes the necessity of transparency (Tonkykh, 2023). From an economic perspective, it is closely linked to the sharing economy, API economy driving platform ecosystems, and network information economy (Kaal, 2021). From a financial perspective, decentralization supports financial inclusion by ensuring access to financial services globally, regardless of location. Moreover, it fosters greater trust and operational efficiency within the financial sector (Sharma, 2024). Finally, from an informational technology perspective, Distributed Ledger Technology (DLT) enhances data integrity, reduces costs, and optimizes processes through IT systems (Jiang, 2022).

Decentralization also extends to the diversification of sources for the supply of various types of goods. By reducing dependency on centralized supply networks, this approach enhances resilience to disruptions in supply chains, a challenge that national economies faced during the Covid-19 pandemic. This diversification not only mitigates risks associated with global crises but also fosters greater adaptability in dynamic market environments. Moreover, such an approach promotes anti-monopolistic market dynamics by encouraging competition and reducing the concentration of power among a few dominant entities. ICT tools play a key role in this process, enabling the rapid flow of information and seamless communication, which are essential for maintaining decentralized and resilient systems.

At the same time, it is essential to examine the role of Big Tech companies within the broader context. While these corporations provide valuable services and technologies, there has been a public backlash regarding their growing influence on the global economy. Their business practices have raised concerns about market monopolization, stifled competition, and the erosion of the tax base through aggressive accounting strategies and tax evasion. This dominance extends beyond their core sectors, such as IT and digital media, to influence both private and public platform technologies (Conyon et al., 2022).

Decentralization enhances flexibility, enabling systems and organizations to adapt swiftly to changing circumstances and address immediate challenges effectively. Flexibility in business decision-making processes enables organizations to effectively coordinate actions, particularly at the operational level, where a prompt response to both predictable workflow changes and sudden disruptions is crucial. (Cognini et al., 2018). Modern organizations operate in an environment characterized by rapid and dynamic changes. Flexibility is a critical prerequisite for mitigating decision-making risks, supported by advanced autonomous computer systems and AI-driven (machine learning) technologies (Jain et al., 2023).

Flexibility is closely linked to adaptability and the resilience of systems to changing processes within enterprises. These concepts are often mutually interrelated. Adaptability, in this context, is understood as the organization's ability to adjust to market conditions, whereas flexibility is more associated with the speed and capability of response. At the same time, the way an organization is adapted to its operating environment directly influences the assessment of its flexibility.

Viewing an organization as a living organism, flexibility could be likened to a personality trait or character attribute, while adaptability corresponds more to the skills and competencies it possesses. These cultivated skills impact how the organization functions, affecting its responsiveness, risk management approach, and overall flexibility. Consequently, this has further implications for the organization's ability to achieve "deeper" adaptation over time.

Flexibility often pertains to short-term reactions to both predictable and unpredictable factors. In contrast, adaptability is a continuous process grounded in foresight and strategy. This process must be preceded and supported by thorough market and industry research as well as the ongoing collection of information from both internal and external sources.

Adaptability encompasses development in both tangible and intangible assets. It pertains to areas such as intellectual capital associated with a company's employees. An organization's adaptability is enhanced by the development of organizational competencies (Bohashko, Bohashko, 2024). These include not only the individual skills and capabilities of employees but also the way they are managed, coordinated, aligned for complementarity, and effectively utilized to deliver value to both the customer and the company. Adaptability also involves a comprehensive system for acquiring new competencies and improving existing ones. This can be achieved through effective recruitment, education, training organization, and career development (Elgezabal et al., 2023).

Competencies are not the only intangible assets within an enterprise that contribute to enhancing its adaptability. Modern IT systems and business applications, when combined with the appropriate human skills, form complementary resources. In the context of Industry 4.0, keeping pace with developments in information technology and leveraging technological advantages are critical. This includes the implementation of new technologies and ensuring their proper integration across all operational areas of the organization. Neglecting this integration may undermine the potential benefits that advanced technologies can bring to the enterprise.

In their pursuit of ever-evolving IT solutions, organizations may overlook the importance of tangible resources, such as physical infrastructure and access to essential utilities like electricity—particularly given the increasing energy demands of advanced technologies. Furthermore, outdated hardware, such as inadequate processors, can pose significant challenges. Adaptability must therefore also address the risks associated with technical debt, which emerges when new solutions are implemented without properly upgrading the underlying hardware or software infrastructure (Patterson, 2023). This debt can hinder the efficient utilization of innovations, ultimately reducing the enterprise's ability to maintain competitiveness.

4. From machine to brain in modern organizations

Agile frameworks are grounded in the premise that cognitive capabilities (such as reasoning and processes inspired by brain functionality) should take precedence over physical labour and motion-based operations, which were central to earlier methodologies like Waterfall. While Waterfall emphasized the optimization of physical strength and sequential workflows, Agile prioritizes intellectual capabilities and adaptability.

Moreover, the human brain's structure and functionality have provided inspiration for advancements in neural networks, critical thinking methodologies, and decentralized systems (see Table 2). This paradigm shift reflects the broader transformation from physical to cognitive drivers of innovation in the context of Industry 4.0.

Flexibility, adaptability, and decentralization in Agile methodology are modelled after the structure and properties of the human brain (e.g., neural signals, pathways, and networks of neurons). Modern technologies such as blockchain, microservices, and increasingly advanced artificial intelligence reflect similar structural principles, characterized by distributed systems, interconnectivity, and adaptive behaviours. These features inherently resonate with Agile principles, as these technologies strive for flexibility, decentralization, and adaptability—core values embedded in the Agile philosophy.

The evolution of project methodology has been influenced by advancements in information and computer technology, as well as the increasing demand for IT-based projects. In table (Table 2), an attempt has been made to detail the specific characteristics of methodology evolution along the transformation path from "machine" to "brain." The terminology "machine" and "brain" is used conventionally, reflecting the nature of work and the structural comparison to machines, often associated with the Waterfall model, and to the brain, representing the structure and function of cognitive processes. Furthermore, technological progress has driven the transition from traditional manufacturing enterprises to smart factories.

Table 2.
From legacy systems to modern Agile architectures

Stage of development	Legacy (machine)	Connectivity	Modern (brain)
Metodology	Waterfall	„WAgile" (Waterfall & Agile)	Agile (from small teams + client to network organisation)
Architecture	Monoliths	SOA (Service oriented architecture)	Micro-services (decentralization)
Infrastructure	Physical servers	(VMs) Virtual machines	Cloud and IoE (Internet of Everything) including IoT and edge computing (decentralization)
Software	Embedded aplications	Separated applications	Containerization
Databases	Closed systems and proprietary databases (closed – trade secret protected)	Comunication Systems (ICTs), Open data and Big Data	Distributed Ledger Technology Cloud native, AI, Blockchain (resilient, flexibility, decentralization)

Cont. table 2.

Integrated systems	H2M (Human to Machines Systems)	Human+ Machines + Technology (communication, integration, networking)	
Team&work	Departments, plans, tasks, documents, centralization	Modules, projects, reports, acts and testing (development, refinement)	DevOps, networking, scrum, design thinking, extreme programming, kanban, lean, problem solving, digital literacy, etc.

Source: own elaboration: based on (Denning, 2018; Elgezabal et al., 2023; Reznik et al., 2020; Bashir, 2018).

In table (Table 2), the key levels of the evolution of design methodologies are presented, highlighting the following areas of change: methodology, architecture, infrastructure, software, databases, integrated systems, and team&work (team dynamics).

The methodology section emphasizes the concept of "WAgile", which combines elements of both Waterfall and Agile approaches. Typically, a project team may work exclusively with Agile while the entire organization follows Waterfall, or only selected principles of Agile methodology may be applied. At the same time, there is an increasing awareness of the benefits offered by Agile methodologies.

The transition from monolithic technology, represented by a monolithic system, involves moving from a structure where the failure of a single component disrupts the entire system. Such systems operate as indivisible units without partitioning. The next step is the adoption of Service-Oriented Architecture (SOA), which is based on consuming discrete services. This progression ultimately leads to microservices, which are distinguished by their modular design, enabling independent development, deployment, and scaling of individual components.

The infrastructure is based on the transition from the organization as a machine to the organization as a brain (the organization understood as a system according to R. Griffin's principles (2004), but nowadays conceptualized as a thinking system (Jung, 2017)). In thinking systems, Industry 4.0 technologies (e.g., VMs, Cloud Computing) play a crucial role. The cloud, initially centralized, is evolving into a decentralized model (Edge Computing), supported by the significant development of Cloud-native solutions. Additionally, machine technologies are achieving greater decision-making autonomy and enhanced collaboration capabilities (M2M).

Software is closely tied to the evolution of architecture, as software cannot exist without an underlying computing infrastructure. This infrastructure has evolved into containerized structures, which are agile, self-contained environments for running applications. Containers enable applications to operate in isolated boxes, enhancing operational security and minimizing the risk of system-wide failures. Due to their increased efficiency, containers often replace virtual machines (VMs).

Integrated systems are embedded within the principles of Industry 4.0 through vertical and horizontal integration, with a strong emphasis on the autonomy of systems in decision-making processes independent of human intervention.

Team & Work – within project methodologies, humans occupy a central position, as even in the case of AI, they oversee algorithms based on machine learning principles (ranging from deterministic algorithms to machine learning). A key assumption in this context is the effort to eliminate the so-called "black boxes" in AI, ensuring transparency and interpretability of algorithmic decisions, which are essential for maintaining human oversight and accountability. Moreover, the relationships between employees are also evolving, transitioning from a traditional hierarchical system to a cooperative and networked approach. In this model, individuals function akin to neurons in the brain, each performing specialized tasks while interacting and influencing one another to collectively achieve project goals.

The above considerations regarding the Waterfall and Agile concepts are presented in two organizational models: "organization as a machine" and "organization as a brain," respectively, as shown in the table (Table 3).

Table 3.
The structure of organization in two approach Waterfall and Agile

Organisation as a machine	Organisation as a brain
Rigid structure with predominantly vertical communication flows	Flexible structure with feedback loops
Task-oriented organization	Project-oriented organization focused on continuous improvement
Tasks divided into stages	Simultaneous execution of multiple task segments
Each subsequent task is executed only after the previous one is completed	Continuous customer-centric improvement
Bureaucracy and task-based reporting	Minimization of documentation to the essentials
Tasks imposed according to the plan	Creativity and creative freedom
Lack of involvement and decision-making autonomy (centralized decision-making)	Employee engagement and decision-making autonomy
Blindness, avoidance of problems	Creative problem-solving
Problems limit development – they are barriers or obstacles	Problems are challenges, solved in real time or incorporated into event scenarios (event prediction)
Detailed instructions, procedures, methodologies, and task execution techniques	Know-how and systems thinking

Source: own elaboration: based on: (Denning, 2018; Mokhtar, Khayyat, 2022).

5. Discussion

New organizational models, systems, and modes of collaboration emerge because earlier approaches fail to adequately address the challenges of a rapidly changing world. Continuously improving existing concepts does not always yield the desired results. At the same time, the implementation of relatively new approaches, such as Agile, can also lead to challenges and introduce chaos.

The transition from hierarchical to networked, decentralized organizations, due to its specific nature, heavily relies on mutual trust among team members and employees within the organization. Treating each unit as a node within a distributed network requires caution regarding Byzantine nodes. Consequently, the concept of resilient organizations has been increasingly discussed in the literature.

The main theoretical contribution of this study is the detailed categorization of the features of the Agile concept within modern organizational contexts. This categorization serves as a foundation for developing a robust methodology tailored to Smart Manufacturing (SM) industrial projects, facilitating the implementation of Industry 4.0 in the industrial sector (Gajdzik, Wolniak, 2022a; Biały et al., 2023).

Agile design aligns closely with the principles of Kaizen, emphasizing continuous improvement through incremental steps. In the context of SM projects, effective teamwork necessitates a strong collaboration between IT specialists and technology experts and machine operators (Gajdzik, 2023).

From a practical perspective, this study highlights the substantial benefits organizations can gain by adopting the Agile concept. Agile methodologies enhance project management capabilities, particularly in IT-intensive initiatives. To improve project outcomes, organizations should focus on key operational areas, such as fostering flexibility in teamwork and strengthening collaborative efforts within IT projects. This approach promotes adaptability, efficiency, and the successful execution of projects in the dynamic environment of Industry 4.0.

In the context of Industry 4.0, creativity plays a pivotal role in design work. It is crucial to understand the principles of creative thinking, develop innovative solutions to technical problems, and apply these solutions in practice. The importance of creativity extends to education, where understanding the Agile concept and its practical applications is integral to producing innovative solutions in technical disciplines such as IT 4.0 or Engineer 4.0.

Gajdzik and Wolniak (2022b), in their analysis of metallurgical study programs in Poland, emphasized the importance of fostering creativity across all areas of knowledge. Their findings highlight that students not only attend lectures but also engage in practical, laboratory, and design exercises. Moreover, subjects related to project management are integral to engineering sciences, as they inherently teach creativity. This focus on creativity is particularly relevant as more companies operating within Industry 4.0 adopt a new innovation paradigm centered on flexibility and customer collaboration.

6. Conclusion

Agile is a contemporary management concept characterized by specific features that support the creation of new products, emphasizing development and continuous improvement. This includes prototyping, with a particular focus on product personalization ("constantly meeting customer expectations"). As a result, flexibility and adaptability become crucial characteristics for organizations aiming to thrive in today's highly competitive market environment. According to Agile philosophy, decentralization is the key to achieving these qualities.

A transition is required from a monolithic system to a more distributed one, where each unit is treated as an autonomous entity. However, it is important to note that these units remain part of a system, forming a network of communication and mutual interdependence.

This gives rise to an analogy between the structure and functioning of two organizational types: the "machine" and the "brain." An organization with a highly hierarchical and bureaucratic structure resembles a machine, where every part has a specific user manual and operational procedures. In contrast, an organization requiring continuous cooperation, quick decision-making, rapid responses to external stimuli, innovation, and a network of interdependent units resembles the neural network of a brain.

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WAITING TIME BEHAVIOR IN A SERVICE MODEL WITH A MULTI-TYPE PROCESSING

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Purpose: In many real-life service systems an arriving customer can obtain different-type processing in dependence on its preferences or requirements. In the paper, a model of a service system with finite waiting room and various types of processing is proposed.
Findings: Analytic method based on integral equations and matrix approach is applied to find a representation for the Laplace transform of the customer waiting time distribution conditioned by the number of customers accumulated in the waiting room initially. Numerical examples are attached as well.
Research limitations/implications: The current study focuses on the analysis of a queueing system with a finite waiting room and multi-type service characteristics under specific assumptions, such as Poisson input streams and hyper-exponential service times. The generalizability of the results may be limited to scenarios adhering to these conditions. Additionally, the transient state analysis primarily addresses fixed initial conditions, which could restrict its applicability to dynamically changing systems or environments. Further research could explore extensions incorporating alternative arrival patterns, varying buffer sizes, and adaptive service mechanisms to improve real-world applicability.
Practical implications: The findings of this study offer valuable insights for the design and optimization of service systems with limited waiting room capacities, such as healthcare facilities, production lines, and network routers. By understanding the transient waiting time distribution, system administrators can better predict potential bottlenecks and implement strategies to minimize customer delays and service interruptions. The mathematical framework can guide decision-making regarding buffer sizing, service process allocation, and workload distribution to improve overall service quality and operational efficiency. Additionally, the approach may aid in the development of real-time control mechanisms for systems experiencing fluctuating demand or unexpected surges in traffic.
Social implications: Efficient queue management is crucial in various sectors that directly impact society, such as healthcare, public transportation, and digital services. By minimizing waiting times, the study contributes to enhancing customer satisfaction, reducing frustration, and improving overall well-being. In healthcare, optimized waiting room capacities can lead to faster service delivery, potentially improving patient outcomes. Similarly, in public services and transportation, reducing delays helps to maintain social trust and ensure equitable access.

The study's findings can also support sustainable development by reducing resource wastage and enhancing system resilience in critical infrastructures, benefiting communities at large.
Originality/value: This study presents a novel analytical approach to evaluating the transient waiting time distribution in finite-buffer queueing systems, employing integral equations and a matrix-based solution framework. Unlike many existing studies focused primarily on steady-state analysis, this research addresses the system's transient behavior, offering a more comprehensive understanding of queue dynamics during non-equilibrium conditions. The consideration of multi-type service times modeled by hyper-exponential distributions further enhances the model's applicability to diverse real-world service processes. The findings provide practical tools for optimizing queue performance in various industries, highlighting the study's contribution to both theoretical advancements and practical implementations.
Keywords: from Poisson stream; queue; service station; time-dependent analysis; waiting time.
Category of the paper: Research paper.

1. Introduction

Nowadays, the customer service process is becoming more and more personalized. This is of course related to the conditions of market competition in which companies from the service industry operate. The desire to attract as many customers as possible forces these companies to make the service process much more flexible and adapt it to certain specific requirements and preferences of customers. As a consequence, the servicing of individual customers may vary significantly, in particular, these differences often relate to the duration of the service itself.

Queueing systems are a very convenient mathematical tool that allows for practical modeling of the behavior of many real service stations. Monitoring of phenomena typical for models related to customer service, such as the accumulation of customers waiting for service, the status of the queue of customers waiting for service, the waiting time for a single customer to start its service, is possible by analyzing the stochastic characteristics of the relevant queueing models, which approximate the behavior of the real system. Of particular importance here are queueing systems with limited capacities of the so-called waiting rooms, i.e. buffers accumulating customers waiting for service. Indeed, in practice, the size of the waiting room is limited in most real service systems. This is, for example, in the case of patients waiting for a doctor's appointment, in the case of components awaiting processing at a specific point in the production line, or in the case of network switch buffers (e.g. Internet routers) in IoT traffic.

One of the most essential stochastic characteristics of each queueing model is the probability distribution of the customer waiting time to start its service (queueing delay, virtual waiting time). This characteristic is crucial from the point of view of ensuring the appropriate level of customer service quality (QoS), and affects the cost of system operation, because keeping customers waiting for service in the buffer is often expensive. Moreover, long waiting times can lead to losses of customers due to buffer overflow.

The literature on queueing models and their practical use in modeling real service systems is huge an,d constantly growing. This applies, in particular, to works devoted to the distribution of customer waiting time. Therefore, the following literature review has been prepared taking into account the most important, in the author's opinion, items, research directions and applications in this field published in recent years.

In (Bellomo, Brezzi, 2020) a discussion on new trends and challenges in traffic, crowds, and dynamics of self-organized particles can be found, in which queueing theory results can be essentially used. A new approach for computing waiting time distribution in finite-capacity queueing models with Markov arrivals can be found in Chaudhry et al. (2023). In Kim (2020) a priority queue with Poisson arrivals is analyzed. Waiting time distributions for different class of customers are investigated there. The problem of bus delays is studied in Sun et al. (2015) by using queueing theory and Markov chain approach. The problem of estimating entropy production from the point of view of waiting time distributions is discussed in Skinner, Dunkel (2021). In Lee et al. (2020) queueing delay distribution in the discrete-type multi-server queue with batch arrivals of customers is investigated. The problem of the impact of skewness of interarrival and service times on the waiting time distribution is studied in Romero-Silva et al. (2020). In Walraevens et al. (2022) asymptotics of the waiting time distributions in the accumulating queue with priority is considered. A rarely used LIFO processing discipline with the auto-correlated input stream in MAP/G/1/N-type model is considered in Dudin et al. (2017), where the representation for the stationary queueing delay distribution is found. Waiting time distributions in an M/G/1 retrial queue with two classes of customers and in a correlated model with exponential interarrival and service times are analyzed in Kim, Kim (2017, 2018), respectively. In Baek et al. (2016) explicit-form representations for transient waiting time distribution in the M/D/1 queue can be found. The waiting time distribution in the D-BMAP/G/1 queueing model is investigated in Samanta (2020). In Bratiychuk, Kempa (2003) a new approach for studying transient characteristics, e.g. waiting time distribution, in a general-type batch-arrival queueing model is proposed. The method is based on the factorization technique and integral equations. Stationary analysis of key performance measures in M/G/n-type model with bounded capacity and packet dropping is done in Tikhonenko, Kempa (2016). In Kempa (2010) the compact-form representation for the actual waiting time in the GI/G/1-type model with batch arrivals is obtained in the transient state of the system operation. A model of a wireless sensor network node operation with a modified threshold-type energy saving mechanism is proposed in Kempa (2019). A proposal of a weight queue active queue management which is based on dynamic monitoring of the current queue size can be found in (Baklizi, 2020) as a tool for reduction congestions at router buffers. In Xie et al. (2023) the problem of adapting of queueing systems to changing model conditions, such as e.g. fluctuations in the number of devices or message sizes, is discussed in the context of using IoT edge computing. The so-called message queues being a way of asynchronous communication for software components or applications by using a shared buffer are investigated in Maharjan et al. (2023). The mechanism of Active Queue Management and its impact on queueing characteristics is considered in Marek et al. (2022). In Solaiappan et al. (2023) an interesting proposal of using of signal distribution control algorithm in minimizing the vehicle queue waiting time can be found, which fits the hot topic of smart cities. In Dimakou et al. (2015) the problem of the estimation of the waiting time distribution in public health care is discussed. Queueing delay distribution for dynamic pickup and delivery problems is analyzed in Vonolfen, Affenzeller (2016). In Bounkhel et al. (2020) a model with server breakdowns is investigated. In Arita, Schadschneider (2015) an interesting queueing model in a microscopic level is considered.

Most of the results obtained for stochastic characteristics of queueing models concern the stationary (steady) state of the system (the case in which time parameter t tends to infinity). In practice, however, the steady state does not always describe the functioning of the system well. For example, each time the service station fails, the system has to stabilize again, and the indicator of the system operation is then the transient (non-stationary) state. The same applies to the analysis of the system operation just after its start-up or just after changing the traffic control mechanism, or the size of the accumulating buffer.

The article analyzes the non-stationary (transient, at a fixed moment t) probability distribution of the customer waiting time in a queueing model with a Poisson input stream of customers and limited waiting room capacity. The traditional, classic FIFO service discipline is applied, according to which customers are served in the order in which they appear in the system. Customers are offered various "conditions" of service, hence the service time for a single customer is modeled using a hyper-exponential distribution with fixed parameters. In Section 2, the considered queueing model is described in detail mathematically. In Section 3, we construct the system of integral equations governing the transient waiting time distribution conditioned by the initial state of the system, i.e. the number of customers waiting for service at the opening ($t = 0$). In Section 4, we write a system of linear equations for Laplace transforms corresponding to the original one, represent it in a matrix form and state the formula for its general solution. Some supplementary results can be found in Section 5. Section 6 contains results of numerical experiments illustrating sensitivity of the transient waiting time distribution on key predefined model parameters.

2. Mathematical model

In the paper, we study a single-channel queueing model with a multi-type service process. Customers arrive into the service station according to a Poisson process with given rate a. The system is equipped with a finite-capacity buffer (waiting time) for accumulating entering customers which must wait for start the service process. The buffer capacity (volume) equals

N-1 places that is a non-random (fixed) value, so the maximum number of customers which are allowed to be present in the system simultaneously equals N (the buffer capacity plus one place for the customer being processed). In the case an arriving customer finds the waiting time being full, it is being lost (it leaves the system immediately without service). The processing is organized according to the natural FIFO (First-In-First-Out) service discipline.

In dependence on their preferences or requirements the entering customers may obtain different-type processing. So, we assume that the service time of a single customer is hyper-exponentially distributed with parameters

$$(b_1, p_1), \ldots, (b_k, p_k), \tag{1}$$

where $b_i > 0, p_i \geq 0$ for $i = 1, \ldots, k$, and $\sum_{i=1}^{k} p_i = 1$.

Thus, the service time of an arriving customer has exponential distribution with mean b_i^{-1} with probability b_i^{-1}, where $i = 1, \ldots, k$, i.e. a customer can obtain k different types of service in the considered model, where k is fixed.

In consequence, the CDF (cumulative distribution function) and the PDF (probability density function) of single customer service time are defined, respectively, as follows:

$$B(t) \stackrel{def}{=} \sum_{i=1}^{k} p_i(1 - e^{-b_i t}) \tag{2}$$

and

$$b(t) \stackrel{def}{=} \sum_{i=1}^{k} p_i b_i e^{-b_i t}, \tag{3}$$

where $t > 0$.

One of the key characteristics of any queueing system is the so-called queueing delay defined for any fixed time t. The queueing delay (also known as the virtual waiting time for service) at fixed time t expresses the time that a customer appearing in the system at exactly time t would have to wait for the start of the service. Obviously, the moment t need not be a real customer arrival moment, hence the term “virtual”.

Denoting by $\tau(t)$the virtual waiting time (queueing delay) at time t, let us introduce the following notation:

$$T_n(t, x) \stackrel{def}{=} \mathbf{P}\{\tau(t) > x \mid \text{initialbufferstate} = n\}, \tag{4}$$

where $t > 0$, $x > 0$ and $n \in \{0, \ldots, N\}$.

Indeed, $T_n(t, x)$ stands for the probability that the waiting time of a customer arriving at time t exceeds x on condition that the system initially (at time $t = 0$) contains n customers accumulated in the buffer (waiting room) exactly. Evidently, for fixed t the probability $T_n(t, x)$is dependent on n essentially.

3. Time-dependent equations

In this section, we establish a system of Volterra-type integral equations for conditional virtual delay distribution defined in (4) utilizing Markov moments in the evolution of the considered queueing system. Indeed, due to memoryless property of interarrival times, consecutive departure moments (time epochs at which customers complete their processing and leave the system) are renewal (Markov) moments in the evolution of the system.

Let us begin with the case of the system being empty at the opening (at time $t = 0$). Denoting by y the first arrival moment after the starting of the system, we obtain the following equation:

$$T_0(t,x) = a\int_0^t e^{-ay}T_1(t-y,x)dy. \tag{5}$$

Indeed, if the first arrival moment y precedes t then, obviously, the probability that the waiting time of a "virtual" customer entering exactly at time t exceeds x is equal to the analogous probability but for the system beginning its operation with one customer present and calculated at time t-y. If the first customer arrives after time t then the probability that the waiting time at time t exceeds x equals 0 (at time t the system is still empty).

Similarly, if the accumulating buffer contains at least one customer at the opening epoch, denoting by y the first service completion epoch (that is a renewal moment in the system evolution) and applying the formula of total probability, we get

$$\begin{aligned} T_n(t,x) &= \sum_{j=0}^{N-n-1}\int_0^t T_{n+j-1}(t-y,x)\frac{(ay)^j}{j!}e^{-ay}\sum_{i=1}^k p_i b_i e^{-b_i y}dy \\ &+ \sum_{j=N-n}^{\infty}\int_0^t T_{N-1}(t-y,x)\frac{(ay)^j}{j!}e^{-ay}\sum_{i=1}^k p_i b_i e^{-b_i y}dy + \theta_n(t,x), \end{aligned} \tag{6}$$

where

$$\theta_n(t,x) = \sum_{k=0}^{N-n-1}\frac{(at)^k}{k!}e^{-at}\int_t^\infty \overline{B}^{(n+j-1)\star}(x-y+t)\sum_{i=1}^k p_i b_i e^{-b_i y}dy. \tag{7}$$

In the formula (7) we use the notation $\overline{B}^{i\star}(u) = 1 - B^{i\star}(u)$, where $B^{i\star}(\cdot)$ stands for the i-fold Laplace-Stieltjes convolution of the CDF $B(\cdot)$ with itself which is defined as follows:

$$B^{0\star}(t) = 1, B^{1\star}(t) = B(t), B^{j\star}(t) = \int_0^t B^{(j-1)\star}(t-u)dB(u), \tag{8}$$

where $j \geq 2$.

The first summand on the right side of (6) refers to the situation in that the first customer leaves the system at time $y < t$ and, simultaneously, just before the moment (y) there is at least one free place in the accumulation buffer. The second summand describes a similar situation with the difference that just before y the buffer is completely saturated. The last summand on the right side of (6) relates to the case in that the first customer departs at time $y > t$. In this situation, if the number of arrivals before t is equal $j \le N - n - 1$, then the probability that the waiting time of a customer arriving to the system at time t is greater than x is equal to the probability that the total service time of $n + j - 1$ customers exceeds $x - y + t$ (the component $\overline{B}^{(n+j-1)\star}(x - y + t)$. If the buffer is saturated at time t, the "virtual" customer entering at this moment is lost and hence we assume that its waiting time equals 0.

4. Linear system of equations for Laplace transforms and its matrix-form solution

In this section, we establish a system of linear equations corresponding to (5)-(6) written for Laplace transforms of the conditional waiting time distribution. Next we transform this system into a matrix form and obtain the representation for the solution.

So, introduce the following notation:

$$\hat{T}_n(s, x) \stackrel{def}{=} \int_0^\infty e^{-st} T_n(t, x) dt \tag{9}$$

where $\mathrm{Re}(s) > 0$.

Due to the fact that

$$\begin{aligned} &a \int_{t=0}^\infty e^{-st} dt \int_{y=0}^t e^{-ay} T_1(t - y, x) dy \\ &= a \int_{y=0}^\infty e^{-(a+s)y} dy \int_{t=y}^\infty e^{-s(t-y)} T_1(t - y, x) dt = \frac{a}{a+s} \hat{T}_1(s, x), \end{aligned} \tag{10}$$

we obtain from (5) the following equation:

$$\hat{T}_0(s, x) = \frac{a}{a+s} \hat{T}_1(s, x). \tag{11}$$

Let us observe that, changing the order of integration, the following representation is true (compare to the right side of (6)):

$$\begin{aligned} &\int_{t=0}^\infty e^{-st} dt \int_{y=0}^t T_r(t - y, x) \frac{(ay)^j}{j!} e^{-ay} p_i b_i e^{-b_i y} dy \\ &= p_i b_i \int_{y=0}^\infty e^{-(a+b_i+s)y} \frac{(ay)^j}{j!} dy \int_{t=y}^\infty e^{-s(t-y)} T_r(t - y, x) dt \\ &= \frac{p_i b_i}{a + b_i + s} \left(\frac{a}{a + b_i + s} \right)^j \hat{T}_r(s, x). \end{aligned} \tag{12}$$

Denoting

$$\beta_j(s) \stackrel{def}{=} \sum_{i=1}^{k} \frac{p_i b_i}{a+b_i+s}\left(\frac{a}{a+b_i+s}\right)^j, \tag{13}$$

and (see (7))

$$\hat{\theta}_n(s,x) \stackrel{def}{=} \int_0^\infty e^{-st}\theta_n(t,x)dt, \tag{14}$$

we can rewrite equations (6) in terms of Laplace transforms as follows:

$$\hat{T}_n(s,x) = \sum_{j=0}^{N-n-1} \beta_j(s)\hat{T}_{n+j-1}(s,x) + \hat{T}_{N-1}(s,x)\sum_{j=N-n}^{\infty}\beta_j(s) + \hat{\theta}_n(s,x), \tag{15}$$

where $n \in \{1,\dots,N\}$.

Now let us transform the system of linear equations (11) and (15) into a matrix form by defining appropriate functional matrices.

Let start with introducing a functional square matrix $\mathbf{B}(s) = \left(b_{i,j}(s)\right)$ of size $(N+1)\times(N+1)$ of coefficients of the system (11) and (15).

Successive entries of the first row of this matrix we define as follows:

$$b_{1,j}(s) \stackrel{def}{=} \begin{cases} 1, & \text{for } j = 1, \\ -\dfrac{a}{a+s}, & \text{for } j = 2, \\ 0, & \text{for } j \in \{3,\dots,N+1\}. \end{cases} \tag{16}$$

Next, for $i = 2,\dots,N-1$let us denote

$$b_{i,j}(s) \stackrel{def}{=} \begin{cases} -\beta_0(s), & \text{for } j = i-1, \\ 1-\beta_1(s), & \text{for } j = i, \\ \beta_{j-i+1}(s), & \text{for } j \in \{i+1,\dots,N-1\}, \\ -\displaystyle\sum_{k=N-i+1}^{\infty}\beta_k(s), & \text{for } j = N, \\ 0, & \text{for } j = N+1. \end{cases} \tag{17}$$

The penultimate row of the matrix $\mathbf{B}(s)$ has the following entries:

$$b_{i,j}(s) \stackrel{def}{=} \begin{cases} -\beta_0(s), & \text{for } j = i-1, \\ 1-\beta_1(s), & \text{for } j = i, \\ \beta_{j-i+1}(s), & \text{for } j \in \{i+1,\dots,N-1\}, \\ -\displaystyle\sum_{k=N-i+1}^{\infty}\beta_k(s), & \text{for } j = N, \\ 0, & \text{for } j = N+1. \end{cases} \tag{18}$$

Finally, let us define entries of the last row as follows:

$$b_{N+1,j}(s) \stackrel{def}{=} \begin{cases} 0, & \text{for } j \in \{1, \dots, N-1\}, \\ -\sum_{k=0}^{\infty} \beta_k(s), & \text{for } j = N, \\ 1, & \text{for } j = N+1. \end{cases} \tag{19}$$

In consequence, the functional matrix of coefficients has the following shape:

$$\begin{bmatrix} 1 & -\frac{a}{a+s} & 0 & 0 & \dots & 0 & 0 & 0 \\ -\beta_0(s) & 1-\beta_1(s) & -\beta_2(s) & -\beta_3(s) & \dots & -\beta_{N-2}(s) & -\sum_{k=N-1}^{\infty} \beta_k(s) & 0 \\ 0 & -\beta_0(s) & 1-\beta_1(s) & -\beta_2(s) & \dots & -\beta_{N-3}(s) & -\sum_{k=N-2}^{\infty} \beta_k(s) & 0 \\ 0 & 0 & -\beta_0(s) & 1-\beta_1(s) & \dots & -\beta_{N-4}(s) & -\sum_{k=N-3}^{\infty} \beta_k(s) & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \dots & -\beta_0(s) & 1-\sum_{k=1}^{\infty} \beta_k(s) & 0 \\ 0 & 0 & 0 & 0 & \dots & 0 & -\sum_{k=0}^{\infty} \beta_k(s) & 1 \end{bmatrix}. \tag{20}$$

Let us define one-column matrices of unknown functions and free terms with $N+1$ rows in the following way:

$$\mathbf{T}(s,x) \stackrel{def}{=} \left[\hat{T}_0(s,x), \dots, \hat{T}_N(s,x)\right]^T \tag{21}$$

and

$$\mathbf{K}(s,x) \stackrel{def}{=} \left[\hat{\theta}_0(s,x), \dots, \hat{\theta}_N(s,x)\right]^T, \tag{22}$$

respectively, where we assume additionally that $\hat{\theta}_0(s,x) = 0$ (compare the right side of the equation (11)).

Referring to (20)-(22), the linear system of equations (11), (15) can be written as follows:

$$\mathbf{B}(s)\mathbf{T}(s,x) = \mathbf{K}(s,x). \tag{23}$$

The representation for the solution of the system (23) can be given in the following matrix form:

$$\mathbf{T}(s,x) = \mathbf{B}(s)^{-1}\mathbf{K}(s,x). \tag{24}$$

5. Supplementary results

In this section, we present some supplementary results related to the considered model, namely the explicit form formula for the Laplace transform of the waiting time distribution in the case of the system without waiting room, the representation for the stationary waiting time distribution and its mean value.

5.1. The model without waiting room

A special case of the considered queueing model is that without waiting time in which the arriving customers can wait for starting their processing, i.e. $N = 1$. Then we get the following simplified formulae for key functional matrices:

$$\mathbf{B}(s) = \begin{bmatrix} 1 & -\frac{a}{a+s} \\ -\sum_{k=0}^{\infty} \beta_k(s) & 1 \end{bmatrix} \tag{25}$$

and

$$\mathbf{K}(s,x) \stackrel{def}{=} \left[\hat{\theta}_0(s,x), \hat{\theta}_1(s,x)\right]^T = [0,0]^T. \tag{26}$$

Because

$$|\mathbf{B}(s)| = 1 - \frac{a}{a+s}\sum_{k=0}^{\infty} \beta_k(s) \neq 0, \tag{27}$$

the only solution of the system (11), (15) is the zero solution. Indeed, if an arriving customer find the server busy with processing it is lost, so its waiting time equals 0. Similarly, an arriving customer that finds the system empty is being processed without waiting, hence its waiting time is 0, too.

5.2. Stationary waiting time distribution

Obviously, since the considered queueing model has finite buffer capacity, the stationary waiting time distribution exists and, moreover, it is independent on the initial buffer state, i.e. the number of customers accumulated in the waiting room at the starting epoch. The formula for the stationary waiting time distribution can then be found by using the Tauberian theorem.

Denoting

$$T(x) \stackrel{def}{=} \lim_{t\to\infty} T_n(t,x) = \lim_{t\to\infty} \mathbf{P}\{\tau(t) > x \mid \text{initial buffer state} = n\}, \tag{28}$$

we obtain

$$T(x) = \lim_{s \downarrow 0} s \cdot \hat{T}_n(s, x) = \lim_{s \downarrow 0} s \int_0^\infty e^{-st} \mathbf{P}\{\tau(t) > x \mid \text{initial buffer state} = n\} dt, \qquad (29)$$

for arbitrary $x \geq 0$.

5.3. Mean waiting time in equilibrium

Denoting by τ the waiting time in the stationary state (equilibrium), its mean value can be calculated as follows:

$$\mathbf{E}(\tau) = \int_0^\infty \mathbf{P}\{\tau > x\} dx = \int_0^\infty T(x) dx, \qquad (30)$$

where the formula for $T(x)$ is given in (29).

6. Numerical results

In this section, we present the results of numerical experiments in which the impact of the input parameters of the considered system on the distribution of the waiting time for service, such as the intensity of customer arrivals, parameters determining the distribution of the service time of a single customer, as well as the initial state of the system. Four different scenarios were considered, in which $N = 2$ and the assumption that the service station offers three different types of service described with exponential distributions with different probabilities, so values

$$(b_1, p_1), (b_2, p_2), (b_3, p_3)$$

are predefined.

The graphs presented below show the behavior of the function

$$T_n(t, x) = \mathbf{P}\{\tau(t) > x \mid \text{initialbufferstate} = n\}$$

in dependence on time parameter t for selected values of the argument x and different initial states n of the accumulative buffer at the opening of the system. Moreover, appropriate stationary waiting time probabilities are found in each case.

6.1. Scenario 1

In Scenario 1, we take into consideration the model in which $a = 2$ and the hyper-exponential service time distribution is defined by the following parameters:

$$b_1 = 1, p_1 = 0.5, b_2 = 2, p_2 = 0.3, b_3 = 3, p_3 = 0.2,$$

So 50% of customers are offered service with an average duration 1, for 30% of customers the mean service duration equals 0.5, and for the remaining 20% it is equal to 0.3 time unit.

It is easy to check that the offered load ρ for such a model equals

$$\rho \overset{def}{=} (\text{Arrival rate}) \times (\text{Mean service time}) = 1.43,$$

so the system is overloaded.

In Figures 1 and 2 the visualization of probabilities

$$T_n(t,1) = \mathbf{P}\{\tau(t) > 1 \mid \text{initialbufferstate} = n\}$$

and

$$T_n(t,0.2) = \mathbf{P}\{\tau(t) > 0.2 \mid \text{initialbufferstate} = n\}$$

are presented, respectively, for $n = 0$ (solid line), $n = 1$ (dashed line) and $n = 2$ (dotted line). The same convention is adopted for all other figures.

Stationary probabilities are the following:

$$\mathbf{P}\{\tau > 1\} = 0.078, \mathbf{P}\{\tau > 0.2\} = 0.223.$$

Let us note that around these values, the curves in each of the graphs stabilize (which illustrates that stationary probabilities do not depend on the initial buffer state). As it can be easily noted, the transient waiting time distribution depends essentially on the initial buffer state n. This dependence is especially noticeable for small values of t.

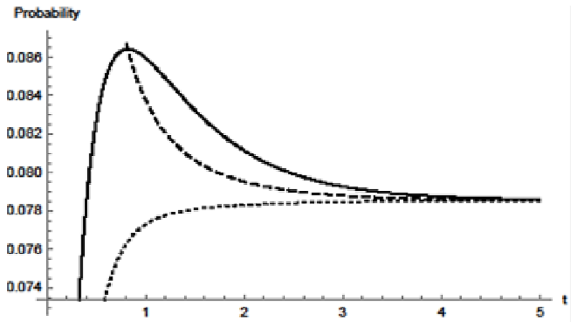

Figure 1. Visualization of probabilities $T_n(t,1)$ for Scenario 1 and $n = 0, 1, 2$.

Source: Authors' own.

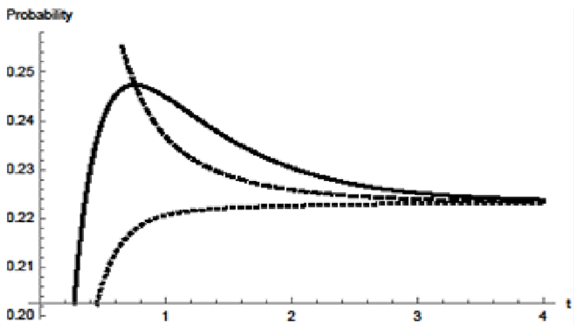

Figure 2. Visualization of probabilities $T_n(t, 0.2)$ for Scenario 1 and $n = 0, 1, 2$.

Source: Authors' own.

6.2. Scenario 2

In this scenario, we take into consideration the same probability distribution of the service time as in Scenario 1 but we take smaller arrival intensity, namely $a = 1$. In consequence we have $\rho = 0.717$.

Similarly to Scenario 1, we present in Figures 3 and 4 transient probabilities $T_n(t, 1)$ and $T_n(t, 0.2)$ respectively, for $n = 0, 1$ and 2.

Appropriate probabilities in the equilibrium of the system are the following ones:

$$\mathbf{P}\{\tau > 1\} = 0.082, \mathbf{P}\{\tau > 0.2\} = 0.227.$$

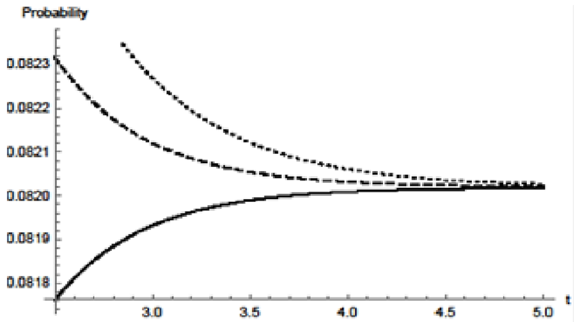

Figure 3. Visualization of probabilities $T_n(t, 1)$ for Scenario 2 and $n = 0, 1, 2$.
Source: Authors' own.

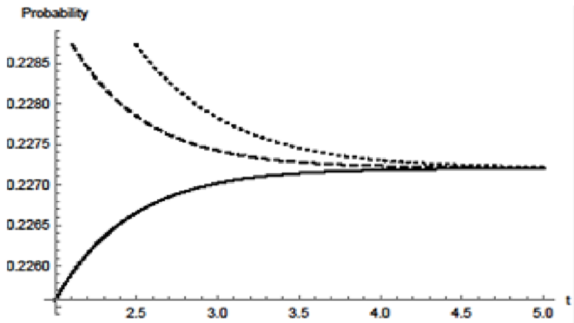

Figure 4. Visualization of probabilities $T_n(t, 0.2)$ for Scenario 2 and $n = 0, 1, 2$.
Source: Authors' own.

Let us note that in the case of a lower offered load (as in Figures 3-4), transient distributions converge slower to the stationary ones. For example, for $t = 4$, the values of probabilities for different values of n differ markedly, while in the case of a greater offered load (Figures 1-2) they are almost imperceptible.

6.3. Scenario 3

In this scenario, the service time distribution is defined by the following parameters:

$$b_1 = 1, p_1 = 0.2, b_2 = 2, p_2 = 0.3, b_3 = 3, p_3 = 0.5,$$

So 50% of customers are offered service with the smallest average duration 0.3, for 30% of customers the mean service duration equals 0.5, and for the remaining 20% it equals 1 time unit.

For such a model we take the arrival rate $a = 3$ and hence the offered load $\rho = 1.550$, so the system is overloaded and in Scenario 1.

Probabilities in the steady state of the system are following:

$$\mathbf{P}\{\tau > 1\} = 0.047, \mathbf{P}\{\tau > 0.2\} = 0.194.$$

Visualizations of transient probabilities $T_n(t, 1)$ and $T_n(t, 0.2)$ are shown in Figures 5 and 6, respectively.

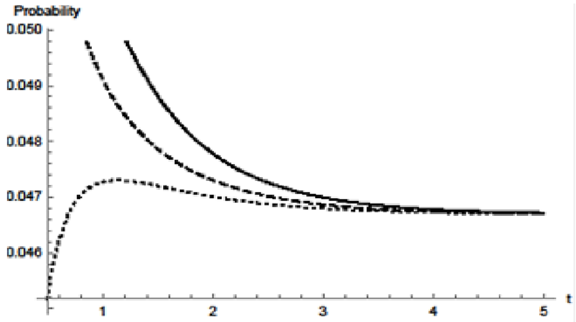

Figure 5. Visualization of probabilities $T_n(t, 1)$ for Scenario 3 and $n = 0, 1, 2$.
Source: Authors' own.

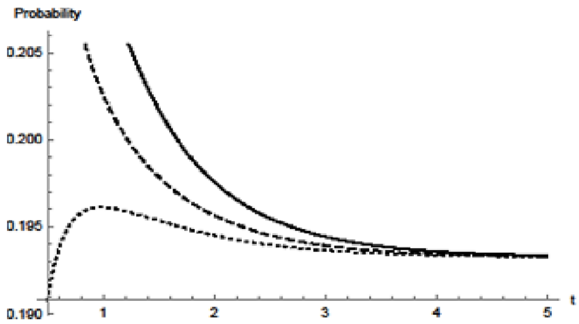

Figure 6. Visualization of probabilities $T_n(t, 0.2)$ for Scenario 3 and $n = 0, 1, 2$.
Source: Authors' own.

6.4. Scenario 4

In the last scenario we take the same service time distribution as defined for Scenario 3 but we take smaller intensity of customer arrivals, namely $a = 2$. In this case we then have $\rho = 1.033$, so the offered load is smaller as in Scenario 3 essentially.

For Scenario 4 we obtain

$$\mathbf{P}\{\tau > 1\} = 0.051, \mathbf{P}\{\tau > 0.2\} = 0.206.$$

Transient probabilities $T_n(t, 1)$ and $T_n(t, 0.2)$ are presented in Figures 7 and 8, respectively.

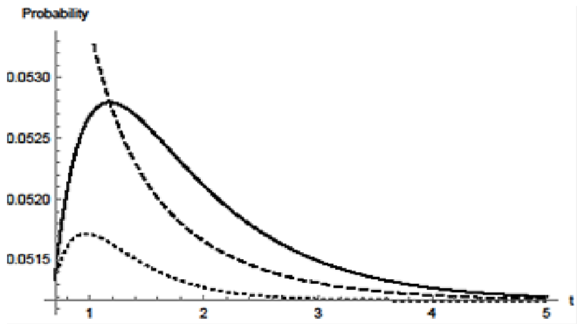

Figure 7. Visualization of probabilities $T_n(t, 1)$ for Scenario 4 and $n = 0, 1, 2$.
Source: Authors' own.

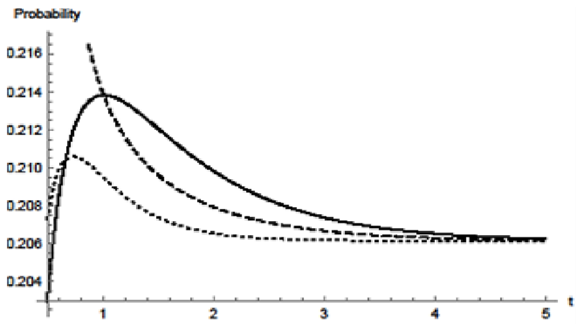

Figure 8. Visualization of probabilities $T_n(t, 0.2)$ for Scenario 4 and $n = 0, 1, 2$.
Source: Authors' own.

Let us note that the service time distribution defined for Scenarios 3-4 is "opposite" to that defined for Scenarios 1-2: firstly the smallest mean service time is the rarest one, in Scenarios 3-4 it is the most frequent. In consequence, "roles" of successive curves representing transient probabilities change too: the behavior of curves obtained for $n = 0$ in Scenarios 1-2 is similar to the behavior of curves obtained for $n = 2$ in Scenarios 3-4, and vice versa.

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THE PROBLEM OF INTERDISCIPLINARITY IN THE AGE OF CLIMATE DESTABILIZATION. WHAT KIND OF KNOWLEDGE DO WE NEED IN THE ANTHROPOCENE?

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Purpose: The paper aims to explore the problem of interdisciplinarity in the context of climate destabilization and to identify the type of knowledge needed in the Anthropocene. It discusses the necessity of integrating knowledge from various disciplines to address the unprecedented challenges posed by climate change.
Design/methodology/approach: The paper employs a theoretical approach, drawing on historical and contemporary examples to illustrate the evolution of knowledge and the need for interdisciplinary integration. It reviews the development of scientific institutions and theories, such as the Earth System Science paradigm, and examines the role of humanities in addressing climate change.
Findings: The paper finds that the fragmentation of scientific knowledge into specialized disciplines has hindered the ability to address complex socio-natural challenges like climate change. It highlights the importance of integrating knowledge from the humanities and social sciences with natural sciences to create a comprehensive understanding of planetary systems. The paper also identifies the underfunding of social sciences and humanities in climate research as a significant barrier to effective climate action.
Research limitations/implications: The paper suggests that future research should focus on developing methodologies for integrating interdisciplinary knowledge and overcoming institutional barriers to such integration. It also highlights the need for more funding and support for interdisciplinary research, particularly in the humanities and social sciences.
Practical implications: The research implies that policymakers and academic institutions should prioritize interdisciplinary approaches to climate research and allocate more resources to the humanities and social sciences. This could lead to more effective climate policies and a better understanding of the human dimensions of climate change.
Social implications: The paper argues that integrating knowledge from the humanities and social sciences can enhance public understanding of climate change and motivate societal action. It suggests that addressing cultural, political, and behavioral aspects of climate change is crucial for achieving sustainability.
Originality/value: The paper provides a unique perspective on the importance of interdisciplinarity in climate research, emphasizing the role of the humanities and social sciences. It addresses scholars, policymakers, and academic institutions interested in developing comprehensive strategies for climate action.

Keywords: Interdisciplinarity, Climate change, Anthropocene, Humanities, Earth System Science.
Category of the paper: Research paper, Theoretical paper.

1. Introduction

Since the concept of the Anthropocene was formulated by Dutch chemist and meteorologist Paul Crutzen and American biologist Eugene F. Stoermer in 2000, reflections from the perspectives of various natural, humanistic, and social sciences have focused on the geological impact of the human species. This new understanding of the human species as a geological force has sharply raised the question of the possibility of creating interdisciplinary knowledge. Although scientific institutions aimed at integrating knowledge from different disciplines have existed since the 1950s—for example, the establishment of the Center for Advanced Study in Behavioral Science (CASBS) at Stanford in 1954—it was only the widespread awareness among scientists and political decision-makers of the unprecedented challenges associated with climate destabilization that significantly increased the visibility of the problem of integrating knowledge. In the face of the urgent need to find answers regarding the relationship between human actions and the functioning of planetary systems, the challenge of bridging the gap between broadly understood humanities and natural sciences has gained a new context.

From the perspective of the humanities, the growing awareness of the necessity to integrate separate scientific disciplines and to bridge the divide between the so-called two cultures is an opportunity for the humanities to gain the status of a field of knowledge essential for ensuring a stable future for our planet. There are increasing analyses linking the failure of climate policy to the disregard of knowledge characteristic of the humanities. Swedish historian Sverker Sörlin explicitly states that our hopes for a more sustainable world are tied to the humanities, as it is cultural values, political and religious ideas, and deeply rooted human behaviors that govern the way people live, produce, and consume (Sörlin, 2012, p. 788).

2. Modes of knowing

By the end of the 1960s, two fundamental models of knowledge were accepted within Western culture. The first model, best expressed by Aristotle, speaks of theoretical knowledge as the highest form of knowledge. Theoretical sciences—such as metaphysics, physics, and mathematics, according to Aristotle—seek knowledge for its own sake, without regard for any practical benefits. Currently, certain elements of this model are present in the concept of basic research. The second model focuses on the practical benefits that knowledge can bring.

The founding father of this way of thinking is Francis Bacon, according to whom the ultimate goal of creating knowledge is to dominate nature.

Currently, in the Anthropocene, we are witnessing the emergence of a new model of knowledge. The goal of this model is no longer solely knowledge for its own sake, nor is it solely the domination of nature. In the Anthropocene, the goal of knowledge is to ensure a stable future for our planet. However, this does not mean that this new model will completely replace the earlier models. It is rather complementary to them. Thus, we are dealing with an expansion of the concept of knowledge, not a simple replacement.

An essential feature of the emerging model of knowledge is the problematization of the culture of scientific specialization. Moving away from the unproblematic acceptance of scientific specialization as the only form of organizing scientific knowledge would be a response to the failure of climate policy, which, according to some researchers, is caused by the epistemic structure of Western science (Oreskes, Conway, 2018, p. 44). According to Oreskes and Conway, the intellectual and institutional organization of science according to disciplines, "in which specialists achieved a high degree of competence related to small areas of inquiry", made it difficult for scientists to recognize the threat posed by climate change because specialists were not aware of those aspects of the problem that did not fall within their fields (Oreskes, Conway, 2018, p. 45). Although interdisciplinary thinking has been developing since the mid-20th century within systems theory, even in these attempts to take a systemic view of reality, social sciences and humanities were rarely combined with natural sciences. Meanwhile, the challenges of the Anthropocene are socio-natural in character, meaning they consist of intertwined components of nature and culture. The specialization of scientific knowledge and the associated division into the so-called two cultures seems to be one of the main challenges of the Anthropocene. The calls for re-evaluating the role of scientific specialization, exploring the possibilities of integrating knowledge from different fields and cultures, are becoming increasingly audible among those dealing with the challenges of the Anthropocene.

3. Fragmentation and integration of knowledge

In Western culture, the process of breaking down knowledge and dividing it into ever narrower areas has been a fundamental undercurrent of its development. However, almost from the very beginning, this trend of enlarging knowledge and dividing it into ever more specialized areas has been accompanied by movements in the opposite direction, involving attempts at synthesis or attempts to seek connections between separated disciplines. At the individual level, the effort to see what specialists confined to their specializations could not see was made by those concerned with general knowledge - polymaths, polyhistorians. Here it is worth mentioning Leonardo da Vinci, for example - in Western culture a figure permanently linked to the idea of comprehensive knowledge. At the supra-individual level, on the other hand, in order to be able to manage the increasing amount of information and turn it into knowledge, there were initiatives of various kinds. Mainly, however, these were initiatives of an institutional and technical nature. The idea of teamwork to complement the research work done by individual scholars was present in initiatives such as encyclopedias, scientific expeditions, laboratories or observatories. A similar role was played by some universities seeking to cultivate the ideal of general knowledge. Nowadays, the idea of so-called Priority Research Areas can be included in this trend of organizing teamwork with the aim of integrating knowledge from different fields. In order to integrate knowledge, efforts of a technical and organizational nature were made - the creation of catalogues, reference books, etc. served to bring some kind of order to the surplus of information. Also important was the search for new forms of knowledge visualization, e.g. in the form of diagrams (Otto Neurath, Patrick Geddes, Paul Otlet) or infographics.

4. Crisis of knowledge and information overload

The key moment of the knowledge explosion (i.e. the expansion of knowledge combined with its fragmentation) was the introduction of book printing technology in the mid-15th century. From that moment on, there is an exponential growth of knowledge. In addition to the sense of intellectual triumph associated with the satisfaction derived from acquiring new areas of knowledge, this process was accompanied by a reflection on the limited nature of our capacity to absorb new knowledge. Very quickly it became clear that there is too much information for a single scholar to absorb. (too much to know). In this context, it is worth referring to numerical estimates to illustrate the thesis of the knowledge explosion. Already at the beginning of the 17th century - according to historians' estimation - some 345, 000 titles had been published. In the middle of the 17th century, a feeling of anxiety about the explosion of knowledge begins to emerge. There is talk of a 'flood of books' or a 'forest in which to be lost'. Robert Burton, an English scholar of the time, wrote of the immense chaos and confusion caused by the profusion of books. Adrien Baillet, a French writer, feared the return of barbarism caused by the deluge of new reading items and the consequent inability to choose books of real value. The motif of the negative impact of an excess of books also becomes a key aspect of Miguel de Cervantes' novel Don Quixote, in which the title character descends into madness as a result of "too much reading".

Print technology is leading to the 'advancement of knowledge' in a relatively short period of time, to the rapid emergence of new areas of knowledge. This process is well illustrated by the growth of knowledge in botany. In 1623, Caspar Bauhin catalogues six thousand plants, while as early as 1682, eighteen thousand were described in John Ray's work. For scholars of the time, the challenge was to incorporate the new knowledge in such a way that both the old knowledge systems and the new ones would not collapse. Referring to this process, historians characterize the seventeenth century as a period of ‘crisis of knowledge’, ‘crisis of the European mind’ or simply ‘general crisis of the seventeenth century’. The response to this process of unprecedented growth in knowledge was the development of specialization. In the seventeenth century, I am dealing not only with the emergence of a new worldview (thanks to Copernicus, Galileo and Newton), but also with the emergence of new scientific disciplines. Descartes' directive in the “Treatise on Method” that, in order to solve problems effectively, they should be broken down into smaller, more comprehensible parts, as this allows for a more thorough and systematic study of each aspect of the issue, became the basic organizational form of knowledge in Western culture. It is at this time that new scientific disciplines begin to emerge - notably physics, astronomy and chemistry. To better illustrate the process of dynamic development of new knowledge, the English historian Peter Burke uses the term ‘knowledge explosion’, which simultaneously combines two processes - the expansion of knowledge and its fragmentation.

5. Loss of a holistic view of the world

It should be noted, however, that many authors of the time associated the fragmentation of knowledge with the threat of losing the overall picture of the world. Johann Heinrich Alsted, a pupil of Comenius considered to be the father of the modern encyclopaedia, feared a ‘fragmentation of knowledge’ (scientiarum laceratio), and his encyclopaedia was to be an attempt to recover the lost unity of knowledge. Alsted's attempts were part of a more general trend of recovering or rebuilding universal knowledge - polymatia, pansofia understood as universal wisdom, general science, omniscience constituted a whole group of terms referring to the desire to go beyond knowledge separated into separate and non-communicating parts. It is worth remembering, however, that the programed for the creation of new knowledge did not have purely cognitive aims, but that certain hopes of a strictly practical nature were attached to it. In addition to the recovery of the lost unity of knowledge, a goal that can be judged as an end in itself, hopes for the ‘reunification of Christianity, the reform of science, the harmonization of philosophy and the creation of a universal language through which disagreements could be reconciled, also played an important role. Pansophy was also linked to even broader goals that included the end of conflicts (the period of the Thirty Years' War), the coming of a “universal reform” that would undo all the evils of this world, and even the hope of a return to the time before the fall of Adam. From today's perspective, such hopes seem unrealistic, but recalling them may exemplify our tendency to see knowledge reform as a miraculous panacea for all evils. There are numerous examples of reforming and improving existing conditions - the abolition of slavery or the emancipation of women can serve as examples - but it is difficult to point to a single factor that is supposed to be responsible for setting these processes in motion. The same is true for the problem of climate destabilization - the creation of interdisciplinary teams of scientists, going beyond specialization, should be one element of a broader strategy, which should include actions of a primarily political nature.

Despite the above-mentioned caveats, the history of responses to the progressive process of specialization can be interesting from today's perspective. First and foremost, it shows today's challenges of seeking links and connections between separate fields of knowledge as part of a long history. This gives today's demands for integrating knowledge from different fields a past that can be used as a kind of legitimization. Lists of scholars and their works, key concepts and rhetoric can become part of the identity of those trying to integrate knowledge from different fields. At the same time, however, learning about the history of attempts to recover the big picture can protect against making past mistakes such as the maximalist, unrealistic goals cited above.

From the perspective of today's challenges, it seems interesting to try to see the connections between different scientific disciplines. For example, Isaac Barrow, in his treatise Of Industry, wrote that ‘one cannot be a good scientist unless one is comprehensive’. General knowledge, he postulated, is related to ‘seeing connections between things and relationships between concepts’, in such a way that ‘one part of science sheds light on another’. The search for common patterns that permeate different areas of reality is still characteristic of the Renaissance. In the later period, the process of specialization and fragmentation of knowledge increased. From the moment Galileo states that mathematics is the only method of reading the Book of Nature, there is a gradual disconnection between the humanities and natural science. By the twentieth century, there is already an impassable gap between the so-called two cultures, and specialized knowledge is recognized as the only form of knowledge worth developing. In his famous 1917 text ‘Science as a profession and vocation’ (Wissenschaft als Beruf), Max Weber writes that ‘science has entered a stage of specialization of unprecedented extent, and that this is an irreversible process. Only in the case of strict specialization can an individual obtain the unshakable certainty that his or her own achievements in the scientific field are indeed fully perfect. The awareness of resignation weighs on all the work we sometimes undertake that extends into the territory of neighboring disciplines (sociologists, for example, have to undertake such tasks constantly)’ (Weber 2002).

6. Earth System Science and transcending scientific specialization

However, since the emergence in the mid-1990s of this twentieth century of a new paradigm within the earth sciences, the so-called Earth System Science, the belief expressed by Weber has become highly problematic. First and foremost, this new paradigm portrays our planet as a unified yet complex and evolving system in which the operation of the whole transcends the sum of the parts. The individual planetary systems - atmosphere, lithosphere, hydrosphere, biosphere and anthroposphere - interact with each other in feedback processes, thereby influencing each other's functioning. This means that understanding how our planet functions requires combining knowledge from different disciplines. A good example is the composition of the Intergovernmental Panel on Climate Change (IPCC), in which we find experts from: natural sciences (climatology, meteorology, oceanography, biology, ecology), social sciences (sociology, economics, political science), technical sciences (environmental engineering, energy, renewable technologies).

The belief that comprehensive knowledge needs to be developed in order to understand how our planet functions was first expressed in 1969 by Buckminster Fuller in "Operating Manual for Spaceship Earth". Referring to the metaphor of a spaceship, Fuller points out that our planet can be understood as an integrally designed device 'which, in order to function successfully at all times, must be comprehensively looked after and serviced' (Fuller, 2014, p. 60). According to Fuller, the further development of specialization makes global society blind to the processes within our planet. For Fuller, this essentially means abandoning efforts aimed at ensuring both the successful functioning of society as a whole and a stable future for our planet. Jùrgen Renn, author of a recent comprehensive monograph exploring concepts of knowledge in the Anthropocene era, believes that it was Fuller's Spaceship Earth Control Manual alongside the somewhat later work of James Lovelock and Lynn Margulis that provided the inspiration for a new paradigm about planetary systems (Renn, 2020, p. 379) - Fuller's philosophical and poetic call for versatility gained paradigm status in the Kuhnian sense around the mid-1990s. (Hamilton, 2017, p. 13).

7. Underfunding of the social sciences and humanities in the context of climate change

When considering the emergence of a comprehensive approach, involving many different scientific disciplines and transcending the barriers of the cultural divide between the humanities and natural sciences, it is important to bear in mind that at present we are still more of a postulate than a description of the actual state of affairs. According to research by Indra Overland, Benjamin K. Sovacool, funding for the social sciences dealing with climate change mitigation is at a dramatically low level. According to their analysis, ‘the activities of 332 organizations allocating research grants through competitions in 37 countries (OECD countries, Brazil, India, China and Russia) did not fund climate change response projects from the social sciences or humanities at all until 1990. Even after that, between 1990 and 2018, climate research was not a priority - less than 5% of all science funding was allocated to it’ (Overland, Sovacool, 2020; Bińczyk, 2024, p. 14). It is imperative to note that within this 5%, the natural and technical sciences received 770% more funding than the social sciences and humanities. One may venture the thesis that, in the context of the urgency of the action to be taken and the seriousness of the threat, there is an appalling ignorance.

When we talk about the dramatic underfunding of the social sciences and humanities dealing with climate change, it is also important to point out the broader context. Despite the formation of a very strong scientific consensus on the anthropogenic nature of climate change in the mid-1990s, there is still a large proportion of Western societies that are skeptical about the need to take action to combat global warming. One of the most important reasons for this is the enormous financial resources devoted to organized campaigns to undermine the scientific consensus. According to an estimate by Peter Brulle, an American sociologist, $900 million a year is spent every year on so-called climate denialism, understood as institutionalized efforts to stop action on climate change. This funding feeds the opposition to climate change. As Brulle writes: ‘Organized opposition to climate change action includes corporations, trade associations, conservative think tanks, philanthropic foundations, advocacy groups, lobby groups and public relations firms whose positions are promulgated through a network of blogs, book publishers and sympathetic media. These different organizations operate in different political and cultural arenas and use different time horizons to achieve a range of goals. These different organizations operate in different political and cultural arenas and use different time horizons to achieve a range of goals. For these reasons, we cannot speak of organized efforts to block or delay climate action in monolithic terms. Rather, these efforts stem from an amalgam of loosely coordinated groups that can be collectively understood as countermovement” (Brulle, 2020).

8. Mobilizing the public for pro-climate action

So, if we are trying to answer perhaps one of the most important questions of the day - how to mobilize society for pro-climate action - we need to bear in mind both the extremely meagre funding allocated to those sciences that deal with the fundamentals of our behavior, and the enormous funding allocated to discourage us from fighting for a stable climate. We can say with a wry smile that the social sciences and humanities are funded extremely generously, but by the wrong actors and for the wrong purposes. After all, climate denialists use knowledge that belongs to the arsenal of the humanities - persuasion and manipulation are part and parcel of the reflection on language, which in Western culture dates back to ancient Greece and the study of rhetoric by the sophists.

On the other hand, scientists themselves often underestimate the role of the rhetorical tradition in communicating climate destabilization. Naomi Oreskes points in this context to two, interrelated, reasons for the failure of climate policy. The first is the lack of communication competence of climate scientists, the second is the misconception held by scientists about the causal nature of science. According to Oreskes' analysis, scientists do not understand the functioning of the mass media. They are convinced that speaking in academic circles, publishing articles in specialized scientific journals and making statements in scientific societies is enough to get governments, corporations and ordinary citizens to start making pro-climate changes. Such a belief, however, is an illusion. Knowledge does not automatically turn into power. For knowledge to start changing the world, it needs an attractive form and a huge commitment. This is where the second mistake of academia can be identified. It is the belief that truth will reveal itself, that truth exists as a kind of eternal idea to which everyone will have access if only they use the right intellectual tools. Based on such philosophical beliefs, experts feel no obligation to participate in time- and energy-consuming debates and disputes. They believe that it is enough to be patient and wait for the truth to reveal itself.

However, it is important to note that in more recent studies, many researchers emphasize the need to include knowledge from the broader humanities in the planning process of climate change mitigation strategies (Smith, Johnson, 2023; Brown, 2022; Green, White, 2021; Taylor, Lee, 2020; Davis, 2019). Ursula K. Heise, a researcher developing the so-called environmental humanities, links the disappointing rate of greenhouse gas emission reductions to the lack of participation of the humanities in the development of pro-climate strategies. Heise writes: 'Without detailed attention to the political, social, cultural, affective and rhetorical forms that the climate problem takes in different communities, simple insistence on the scientific facts will often remain politically pointless, (...)' (Heise, 2016, p. 24). A similar opinion is expressed by the Swedish hisotician Sverker Sörlin: "Our belief that science alone could deliver us the planetary quagmire is long dead. For some time, hopes were high for economics and incentive-driven new public management solutions. … It seems this time that our hopes are tied to the humanities. … in a world where cultural values, political and religious ideas, and deep-seated human behaviors still rule the way people lead their lives, produce, and consume, the idea of environmentally relevant knowledge must change. We cannot dream of sustainability unless we start to pay more attention to the human agents of the planetary pressure that environmental experts are masters at measuring but that they seem unable to prevent" (Sörlin, 2012, p. 788). The recipe, therefore, for pro-climate mobilization seems simple - to increase the emphasis on the humanities, broadly understood, when developing strategies to mitigate climate change. It is worth noting, however, that this requires undermining the specialization-based knowledge model itself, which may be controversial.

9. Challenges of knowledge integration and recommendations

Advocates of specialization argue that close knowledge in narrow fields is essential for achieving breakthroughs and innovations, as it allows for more precise and advanced research. In the course of our argument, we have tried to show that this is not about moving away from specialization, but only about complementing it. The social sciences and humanities can be a complementary component and fulfil those roles that specialized and narrow fields are unable to fill. Global warming is not a strictly natural phenomenon, but a kind of qusi-object consisting of processes of a natural nature and components originating from human activity. Although the direct causes are carbon dioxide emissions and massive deforestation, at a deeper level the functioning of the socio-economic system, the conception of nature in the natural sciences or religious beliefs are pointed to as factors conditioning the way our civilization functions, in which nature is treated exclusively as a resource (Knosala, 2021).

Although interdisciplinarity is increasingly seen as a necessity in the Anthropocene era, its implementation is nevertheless facing resistance from traditional academic and institutional structures that are deeply rooted in the epistemic structure of Western science based on specialization. Many authors highlight the challenges of developing interdisciplinary research. These include the difficulties in coordinating and integrating different research fields, the underfunding of the social sciences and humanities, and the difficulties associated with differences in methodology, language and culture of different research fields. Integrating methodological differences, searching for common concepts or learning the skills to function in different research cultures requires time, resources and a change of approach in education and research. There is a need to promote openness towards other scientific disciplines and organizational support to enable the exchange of experiences between disciplines. The Priority Research Areas operating at Polish universities under the Initiative for Excellence - University Research (IDUBA) programme since 2020 are a source of hope in this regard. Most Polish universities have POBs related to climate protection. It is also worth noting that some researchers associate hopes for a more sustainable future with information and communication technologies, which can support sustainable development, while digitalization itself can influence governance processes in the context of climate change (Kuzior, Ketller, 2022). There is no doubt that cognitive technologies bring with them the hope of smoothly integrating separate scientific disciplines. Recommendation systems based on deep machine learning can significantly facilitate the fusion of knowledge from different sciences. However, it should be borne in mind that the primary challenge of knowledge integration in the Anthropocene is barriers of an ontological nature. At issue is the division between nature and culture that underlies the organization of knowledge. It is difficult to imagine today that cognitive technologies will bail people out of philosophical discourse. In addition, the effects of philosophical discourse - new concepts related to reflection on theoretical difficulties, a new vocabulary of terms or, ultimately, a new way of looking at the world - must be incorporated into the collective consciousness through mass culture, works of art, literature and education. Such a process is usually slow and should occur organically. It is difficult to imagine that we will be bailed out by cognitive technologies in this aspect as well, although they can undoubtedly support the above-mentioned processes.

Controversy also surrounds how to assess and measure the success of interdisciplinary research projects compared to traditional specialized research. In traditional specialized research, success is often measured by the number of publications, citations or grants won by researchers. In interdisciplinary projects, these indicators may not capture the full picture, as the projects often span different scientific disciplines, making direct comparison difficult. In addition, interdisciplinary projects - and this is especially true for climate change mitigation - may only produce results after a longer period of time, making short-term evaluation difficult. The difficulty of establishing reliable, verifiable indicators in the short term may influence the reluctance of grant-makers to establish grants for interdisciplinary projects.

10. Summery

The paper employs a theoretical approach, drawing on historical and contemporary examples to illustrate the evolution of knowledge and the need for interdisciplinary integration. It reviews the development of scientific institutions and theories, such as the Earth System Science paradigm, and examines the role of humanities in addressing climate change. The article finds that the fragmentation of scientific knowledge into specialized disciplines has hindered the ability to address complex socio-natural challenges like climate change. It highlights the importance of integrating knowledge from the humanities and social sciences with natural sciences to create a comprehensive understanding of planetary systems. The paper also identifies the underfunding of social sciences and humanities in climate research as a significant barrier to effective climate action. The research implies that policymakers and academic institutions should prioritize interdisciplinary approaches to climate research and allocate more resources to the humanities and social sciences. This could lead to more effective climate policies and a better understanding of the human dimensions of climate change. The paper argues that integrating knowledge from the humanities and social sciences can enhance public understanding of climate change and motivate societal action. It suggests that addressing cultural, political, and behavioral aspects of climate change is crucial for achieving sustainability. The article provides a unique perspective on the importance of interdisciplinarity in climate research, emphasizing the role of the humanities and social sciences. It addresses scholars, policymakers, and academic institutions interested in developing comprehensive strategies for climate action.

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SUSTAINABLE DEVELOPMENT AND ORGANIZATION MANAGEMENT ON A SELECTED EXAMPLE

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Purpose: The aim of this article is to present solutions in the field of sustainable development and to showcase best practices in this area using the example of a native, thriving company, such as Press Glass Holding SA.
Design/methodology/approach: The study was based on purposive sampling. An inquiry was sent to the company regarding their willingness to participate in the study. The thematic scope was presented, and participation was voluntary. The research tool used was a survey questionnaire. Contact with the company was conducted via email correspondence, and a meeting with the management of the establishment took place.
Findings: The study can serve as a small contribution to presenting good managerial practices for other companies and indicates the importance of applying principles of sustainable development. Based on the study, areas requiring special attention and places in the company management have been identified. The company's actions can serve as inspiration for other organizations to implement principles of sustainable development.
Research limitations/implications: This study could be expanded to include a significantly larger number of enterprises from the territory of the Republic of Poland. This would enable the creation of sustainable development principles tailored to Polish conditions. The main weakness of the study is the presentation of only one company without comparison with others in the same industry.
Practical implications: This study could serve as a starting point for the creation of universal principles of sustainable management in Polish conditions for developing companies. It can serve as inspiration for undertaking such actions.
Social implications: Better management in implementing principles of sustainable development and respecting the environment contributes to improving the work and life of future generations by showing respect for the natural environment and its resources.
Originality/value: Presenting a company that successfully implements principles of sustainable development in its activities, achieving market successes, and enjoying the recognition of employees.
Keywords: Sustainable development, green deal, management, internal marketing, corporate social responsibility.
Category of the paper: Research paper, case study.

Introduction

We are witnessing an increasing awareness of climate change and the need to build in a sustainable manner. It is extremely important to maintain the highest standards and norms regarding both the construction, functioning, and subsequent dismantling of investments, which close the building's life cycle. A holistic approach facilitates the implementation of principles of a circular economy and reduces the carbon footprint. Therefore, the construction sector is one of the key targets of the European Commission's policy on the circular economy: a renewable economic system where resource and energy consumption is minimized. The necessary direction of development is to strive for buildings with a zero carbon footprint. The Paris Agreement of 2015 makes this issue clear: by 2050, it is necessary to decarbonize the global economy, and construction is one of its pillars. Buildings require enormous amounts of energy, which contributes to greenhouse gas emissions. One of the key elements in building construction is glass components such as windows, glass facades, etc. This issue is examined in his article by, among others, M. Wojas (Wojas, 2020, pp. 61-72).

This approach to the problem is facilitated by principles of sustainable development. Deepening imbalance leads to exceeding the tolerance limits of nature and the uncontrolled growth of social problems. To prevent this, changes are necessary in many aspects of human activity, including both consumption and production. Management should play a crucial role in these activities. Sustainable management has been written about by, among others, S. Cohen (Cohen, 2011, p. 146). A. Pabian has developed issues in this area regarding individual management functions (Pabian, 2013, pp. 3-8).

Literature review

The United Nations is making efforts to construct a transparent set of global goals aimed at saving the planet and improving the lives of people. Agenda 21, adopted at the "Environment and Development" conference in Rio de Janeiro in 1992 (in Poland in 1993), emphasized the interconnections between the three dimensions of sustainable development: economic, social, and environmental (UN Conference Documents, June 3-14, 1992, and Earth Summit, Warsaw 1993). In 2000, the Millennium Summit was held in New York, during which eight goals related to sustainable development were formulated (http://www.un.org.pl/…). 189 UN member states committed to achieving these goals by 2015. The Millennium Development Goals (MDGs) focused on the social dimension through actions, among others, in the environmental and economic spheres, aiming to reduce poverty, hunger, diseases, and to improve human rights. Unfortunately, over the course of fifteen years, new financial, economic, military, food, and energy crises have emerged, and the interconnections between them have also become more complicated. As a result, the MDGs were not achieved on a global scale. During the conference in Rio de Janeiro in 2012, the document "The Future We Want" was created (The Future We Want…, 2012). It contained the framework for the planned Sustainable Development Goals, intended to ensure economic transformation, including the eradication of poverty, the establishment of the rule of law, and the protection of nature. The United Nations Conference on Sustainable Development in September 2015 confirmed the necessity of political commitments by the international community in pursuit of sustainable development, following the principles of Agenda 21, including the principle of common but differentiated responsibility. The summit's final document contains guidelines for achieving sustainable development as a way to increase the prosperity of current and future generations in all countries – the 17 Sustainable Development Goals. They are based on minimizing types of consumption and production that have negative external effects, while simultaneously striving to maximize types of consumption and production that have positive external effects. Examples of minimizing negative external effects include reducing environmental pollution, while examples of positive external effects include technology adaptation, reducing food waste, and increasing energy efficiency (Reflection Paper…, 2019). Changes in consumption patterns can drive the creation of new technologies necessary for sustainable development and their adoption and dissemination at the fastest possible pace. Success in implementing these changes will require significant reorganization of the economy and society and promoting changes in lifestyle. Understanding the connections between these trends and the associated changes in economic, social, and environmental conditions has become essential. In this broad context, climate and environmental protection must become a global endeavour – a scale embodied by the 17 UN Sustainable Development Goals. The UN Sustainable Development Goals (SDGs) were established as a "shared blueprint for peace and prosperity for people and the planet, now and into the future". Since buildings account for 40 percent of CO2 emissions, transforming existing buildings or constructing new eco-friendly ones is a responsible step in the right direction (Wojas, 2020, p. 64).

It is also necessary to transform consumer societies into sustainable societies based on responsible production and consumption. The need for such transformations began to be strongly emphasized in the field of economic sciences already in the 1980s (Pabian, 2013). Sustainable development economics aims to sustainably preserve natural resources. The Earth is seen as a closed, non-materially growing system. Thus, the primary task of sustainable development economics is to solve economic, ecological, and social problems (Rogal, 2010, pp. 20-24, 130-134). Management plays a crucial role in achieving this task through organization managers. Articles by A. Pabian (Pabian, 2013), S. Cohen (Cohen, 2011, pp. 1-13), who criticizes traditional management and recommends sustainability management principles, address issues related to managing organizations sustainably. B. Bossink deals with aspects of eco-innovation and sustainability management (Bossink, 2012, pp. 1-4). According to A. Pabian (Pabian, 2017), sustainable management is a process of achieving organizational goals while considering the principles of sustainable development. Achieving sustainable management will be possible through the work of sustainable personnel and the involvement of other sustainable organization resources. Managers at all levels play a particularly important role here. However, their attitudes and beliefs should be based on values rooted in the following orientation: taking responsibility for the state of the Earth, acting for future generations, focusing on the future, balancing economic, ecological, and social goals, preferring sustainability over growth, minimizing negative impacts on the environment and humans (Pabian et al., 2013, pp. 6-7). Aspects related to sustainable management are also addressed by G. Haugen (Haugen, 2014), M. Epstein, A. Buhovac (2014), M. Jones (Jones, 2010), and the previously cited A. Pabian (Pabian, 2011, 2015a, 2015b, 2016).

The above assumptions seem to be met by the researched company Press Glass Holding SA, headquartered in Konopiska near Częstochowa, Silesian Voivodeship (https://www.pressglass.com/pl/holding/).

Discussion

To familiarize solutions in the field of sustainable development and present best practices in this area using the example of a native, thriving company such as Press Glass Holding SA, a survey and interview were conducted. Company documents were also reviewed. The study was based on purposive sampling. An inquiry was sent to the company regarding their willingness to participate in the study. The thematic scope was presented, and participation was voluntary. The research tool used was a survey questionnaire. Contact with the company was conducted via email correspondence, and a meeting with branch managers took place. The questionnaire comprised 26 open-ended questions, for which comprehensive responses were obtained. Press Glass Holding SA was established in 1991. The company is privately owned and operates as a joint-stock company. It conducts holding and financial activities, providing services to other subsidiary companies. The company's headquarters are located in Konopiska, Silesian Voivodeship. Press Glass Holding SA is the sole shareholder of Press Glass Sp. Z o.o., Press Glass Z. o.o., Press Glass UAB, the Press Glass UK Group (which includes Glass Systems UK and Press Glass, Inc.), and AMC Aviation Sp. Z o.o. It employs 5060 people, each of whom has clearly defined rights and responsibilities. Functional and substantive dependencies overlap, and the hierarchical structure of the company is clear and transparent. Individuals involved in the management process continuously enhance their competencies in this area. The company systematically conducts market research in the form of market analysis and utilizes market research agency reports. Management in the company is referred to as laissez-faire management, meaning that leadership style is characterized in such a way that leaders do not tend to micromanage their employees or overly involve themselves in tasks already assigned to employees. They allow employees to take initiative in projects, trusting their creativity, training, and experience. There is a high level of trust in employees' competencies. Although delegating leaders usually do not engage in decision-making by employees, they provide guidance in the form of mentoring and assume responsibility when needed. This leadership style works best in an organization where professional, qualified, and motivated employees work (https://www.studysmarter.co.uk/…). The company's main website presents the main mission and goal of the company, as well as a code of conduct. "Our responsibility as an employer, employee, and business responsibility is to act in accordance with PRESS GLASS values, which are very important to us. We care about embodying them in daily relationships with our employees and business partners. We want those who cooperate with us to share the values we follow" (https://cdn.pressglass.com/…). Responsibility is divided into 3 categories:

- employer towards employees (We treat employees equally and with respect, We protect personal data; We avoid professional dependencies in the case of family members;
- employees towards employer (We adhere to the provisions of the Labor Code and other procedures; We respect the employer's property and care about its image; We protect data and do not disclose confidential information; We avoid conflicts of interest; We care about the quality of our work);
- company towards business partners (We care about relationships with business partners; We responsibly decide on the choice of a business partner; We do not disclose confidential information; We comply with antitrust laws; We adhere to the principles of giving and receiving gifts; We prohibit corruption; We are friendly to the environment) (ibid.).

The mission of Press Glass Holding is: strengthening the competitiveness of our Clients by satisfying their requirements. We offer added value to our Business Partners, which we understand as enriching our products, services, and solutions with new, better features and values. (https://www.pressglass.com/pl/o-firmie/) Additionally, on the main page of the company's information, attention is paid to environmental protection: "To reduce our impact on the environment, we are constantly making changes in the production of products and in our habits" (https://www.pressglass.com/pl/o-firmie/) In line with such a declaration, it is not surprising that the company conducts a series of activities related to ecology and sustainable development. The company's main website lists the Agenda 21 goals being pursued, including:

- GOAL 3: Ensure healthy lives and promote well-being for all at all ages.
- GOAL 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.
- GOAL 8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.

- GOAL 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.
- GOAL 11: Make cities and human settlements inclusive, safe, resilient and sustainable.
- GOAL 12: Ensure sustainable consumption and production patterns.
- GOAL 13: Take urgent action to combat climate change and its impacts.
- GOAL 17: Strengthen the means of implementation and revitalize the global partnership for sustainable development (https://www.pressglass.com/pl/zrownowazony-rozwoj/).

One of the main initiatives regarding solutions related to sustainable development undertaken by Press Glass SA is the implementation of a closed-loop economy. Every waste is treated as secondary raw material. The main waste is glass cullet. It is sent directly (Radomsko branch) or indirectly (other plants) back to the glassworks as charge material for the glass furnace, where new glass sheets are melted again. Glass cullet in Radomsko has the status of a by-product. Additionally, the main components necessary for the production of laminated glass, such as sealing compound, are processed on-site for full utilization. Due to the density of the compound, it would not be possible without a special installation. Other production wastes are recycled/recovered or returned to the manufacturer for reprocessing. The "zero waste to landfill" policy has been implemented. Other pro-environmental initiatives related to sustainable management include:

- reporting carbon dioxide and other greenhouse gas emissions (e.g., to the international CDP database);
- installation of photovoltaic installations in plants (in the Croatian plant, it covers almost 20% of the total demand);
- machines are constantly optimized and replaced with newer ones for energy efficiency and increased efficiency;
- in the plants, 90% of the gas forklift fleet has been replaced with electric forklifts;
- the transport fleet is one of the most modern; loading is fully optimized, and there are no "empty" runs;
- in one of the plants, a system for full recovery of heat from the tempering furnace has been implemented to reduce gas usage for heating;
- Integrated Environmental Management System 14001 and Risk 9001 have been implemented;
- Press Glass products have special Environmental Product Declaration declarations, which present the values and units characterizing the product's impact on the natural environment; the Main Headquarters building is the highest energy-efficient class building;
- Press Glass glazing is installed in buildings that seek BREAAM/LEED certification;
- in the production plants, energy efficiency is constantly being increased, confirmed by obtaining White Certificates. Closing the waste loop and preventing its generation has been taking place at Press Glass for years and is a quite natural element of the raw material management process.

All initiatives related to sustainable development and reducing the company's impact on the environment are part of Press Glass's business strategy. Increasing the energy efficiency of machines is done in real-time, and new projects regarding innovation are being developed. Work is constantly being done to define specific goals for reducing the carbon footprint and media consumption. Among the biggest problems of the company related to the closed-loop economy and other elements of sustainable development, one can include:

- lack of data in the supply chain,
- the process of recycling laminated glass is a challenging one,
- lack of appropriate recovery technologies in the region served by the waste recipient,
- lack of awareness and education regarding sustainable development,
- a large scale of greenwashing.

To improve management actions, the company continuously conducts marketing activities to inform about sustainable development efforts. Such actions are communicated on the website, during employee training sessions, and noteworthy initiatives are also shared on social media. However, no marketing research is conducted regarding the company's reception as socially responsible. This is mainly due to the nature of Press Glass' B2B business and its direct contacts with contractors. Data on competitors' activities are continuously collected and analysed. To develop in line with the implementation of technological innovations, the company participates in trade fairs and conducts development activities directly with equipment suppliers.

Press Glass focuses on continuous development, constantly increasing its executive capabilities. The continuous development of production facilities, sales markets, and competence growth allows for even better service and offering a wider range of products of increasingly higher quality.

The company has modern production facilities. Their location, production capacity, range of certifications, and assortment make it the only one to have adapted to the market demand in such an efficient manner. Each plant specializes in manufacturing a different assortment, but together they form an efficient system of connections. In line with the assumptions of the company's management policy, it uses the most modern equipment. The machine park is constantly being expanded and modernized. The company participates in testing and implementing new technologies. It helps to indicate development directions to its equipment suppliers.

As part of its sustainable management policy, Press Glass Holding SA provides individual support, building with customers an individual, satisfying both parties, long-term cooperation model.

Press Glass is open to introducing new products and solutions, with customers being their inspiration. A dedicated team managing orders ensures efficient and timely flow of information at every stage. Comprehensive and timely service is guaranteed, and business partners can count on a quick response, even in critical moments.

The company has its own fleet of trucks and collaborates with experienced international carriers. Every month, the company's products are transported over a total distance exceeding 1 million kilometres.

Press Glass is a partner of branded window manufacturers, where the increased quality of products is a necessary condition for cooperation. The company's products are adapted to the requirements of general European and American standards, regulations applicable in individual countries, and individual agreements with customers. The entire European product range meets CE marking requirements, and all plants are covered by ISO 14001 environmental management systems and ISO 9001 quality management.

Press Glass is financially and organizationally independent, allowing it to offer products from all major suppliers. It provides independent and objective advice on selecting components for products.

In addition to its core business, as part of its sustainable development policy, the company conducts educational, cultural, and charitable activities, achieving goals 3 and 4 of the Agenda.

- Environmental actions - goal 3, Agenda 13.
- Sports - goal 3.
- The company's environmental and social responsibility are goals: 8, 9, 11, 12, 13.
- Quality management - goals 8, 9, 11, 12, 13.
- Emission neutrality: goals 8, 9, 11, 12, 13.
- Values and "Code of CONDUCT": 4, 8, 11, 12, 13.
- Responsible production: goals 4, 8, 11, 12, 13.

The biggest limitation, apart from the current technological capabilities for Press Glass Holding SA, is the limited financing possibilities that do not allow the company to develop according.

Summary

Undoubtedly, Press Glass has been directing its efforts towards sustainable development for many years. By implementing state-of-the-art technological solutions, it is able to meet the expectations and needs of its customers. It delivers energy-efficient products that maximize the use of natural light. The company is responsible for ensuring that buildings create environments that are as conducive to life, work, and development as possible. Transparency of actions is one of Press Glass's fundamental values. Therefore, the company has decided to report on environmental matters according to the highest global standards. Data regarding Press Glass is included in the international CDP database, which includes information on carbon dioxide emissions, among other things. Press Glass's carbon footprint has been calculated using the Greenhouse Gas Protocol, enabling it to have full control and monitoring of the sources of greenhouse gas emissions emitted by its production facilities. The new Press Glass facilities, scheduled to start operating between 2023 and 2026, will be low-emission facilities, partly due to the use of renewable energy sources. In existing facilities, actions are being taken to reduce emissions by installing renewable energy installations and implementing closed-loop economy strategies. Press Glass continuously expands its product offering to meet market needs. Through its policies and appropriate actions, it contributes to real changes aimed at protecting the environment. Glass is the main building material for sustainable infrastructure. According to the words of the company's owner, Arkadiusz Musiał, "There are no modern buildings without modern windows and glass facades. Thanks to this dependence, we become one of the main shareholders of green construction. We spend the most time in buildings - we live, work, and rest in them. The world is changing before our eyes. Urbanization, energy requirements, climate change - we must constantly adapt to the dynamic reality. Life and work are better in beautiful places. Europe and North America are on the brink of a green turnaround, in which glass and other modern materials will play a key role. Press Glass is prepared to participate in this process because glass undoubtedly has a bright future. As a modern and conscious company aware of ongoing social changes, we also want to contribute to shaping a better and more civic society, understanding that building a modern and efficient economy requires development and engagement from each of us. I am convinced that striving for a higher standard of living should come through investment in entrepreneurship and civic education, also understood as responsibility for the state of the country. That is why I have created the Foundation for Economic Freedom, which supports valuable initiatives in four areas: economic liberalism, education for the future, democratic rule of law, and Poland in the European Union. In addition to freedom and a free market, building a well-functioning company requires a community of values such as honesty, commitment, respect, trust, and discipline. We build our company's reputation on them every day" (Muś, Sustainable Development, Press Glass - company documents - 2023). These words are supported by specific actions that fit precisely into activities related to sustainable development. The company's results also indicate that such an approach is beneficial and fully allows the company to utilize its potential, especially when its management policy is conducted in a consistent manner.

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EVALUATING PERFORMANCE AND MEMORY TRADE-OFFS IN DYNAMIC PROGRAMMING: A COMPARATIVE STUDY OF TABULATION AND MEMOIZATION TECHNIQUES

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Purpose: This research aims to conduct a diverse quantitative analysis of the two main dynamic programming techniques: Tabulation and Memoization on the Word Break and Minimum Sum Path in a Grid problems. The results should provide insights into the dependencies and entanglements in which one technique evinces superior results or both present regularly similar outputs depending on the input.
Design/Methodology/Approach: The study was carried out using Swift programming language and Xcode IDE to perform a series of tests on Tabulation (bottom-up approach) and Memoization (top-down approach) to solve various computational scenarios of the Word Break and Minium Sum Path in a Grid problem. To recognize the performance of each technique, we analyzed the data using R and RStudio.
Findings: Memoization leverages its caching mechanism that stores the results of previously calculated problem subproblems. In scenarios when the number of overlapping subproblems is significant, it offers a superior execution time over Tabulation. Nonetheless, as the complexity increases and the number of overlapping subproblems lowers, Memoization fails to provide consistent results and may lead to unpredictable memory usage. In those scenarios, Tabulation offers predictable memory usage with expedited execution times, which is beneficial in resource-constrained environments. Figures 1, 2, 3, and 4 present optimized solutions to the Word Break and Min Sum Path in a Grid problems, solved using Tabulation and Memoization. Figures 5 and 6 present memory usage and execution time achieved with our testing scenarios.
Originality/Value: The research gives us a practical understanding of scenarios in which Tabulation or Memoization is a better algorithm optimization technique.
Keywords: Tabulation, Memoization, Dynamic Programming.

1. Introduction

Dynamic Programming relies on decomposing a complex problem into overlapping subproblems, where each subproblem gets solved only once. The main two techniques in Dynamic Programming are Tabulation, known as the top-down approach, and Memoization, known as the bottom-down approach.

The tabulation technique relies on iteratively solving the smallest subproblems and storing their results in a so-called dp table. These results are then used to tackle larger subproblems progressively. The solution to the original problem is obtained from the final entry. The "bottom-up" approach originates from this exact characteristic – working way up to the solution to the original, much more complex problem (Levitin, 2011).

On the other hand, the Memoization technique begins with the original problem and then breaks it down into smaller subproblems. Results of these subproblems are stored in a so-called memo and retrieved in case of needing to stumble upon the same function's parameter values, which would produce an already computed result (Kleinberg, Tardos, 2005; Haftmann, Nipkow, 2020). Such behavior evinces a "top-down" approach as we work down to the smallest subproblems.

It's essential to pick a technique based on the problem characteristics and constraints. We should pay attention to problem structure, resource constraints such as available amount of memory, the efficiency of the chosen programming language with recursion, and initialization requirements such as initializing a dp table. A deep understanding of these characteristics will allow us to leverage these techniques' strengths and provide the well-optimized solutions.

2. Methodologies

Our problems of choice are the Word Break and the Minimum Sum Path in a Grid problems. We assess how each technique will impact memory usage and execution time and determine if the performance is predictable.

The Word Break problem is based on a variable-length substring, which makes it a prominent recursive problem. Meanwhile, the Minimum Sum Path in a Grid problem has a grid-based structure, where subproblems directly depend on neighboring cells. Some number of overlapping subproblems characterize both problems.

The Word Break Problem asks if a given string can be segmented into dictionary-defined words. This problem is a foundation of natural language processing (NLP), language modeling, text parsing, and word segmentation. Their implementation may be found in solutions such as spell checkers, autocomplete systems, or speech-to-text algorithms, where text needs to be broken down into a set of meaningful words.

In the Minimum Sum Path in a Grid Problem, each cell of the 2-dimensional grid has a value associated with it. The objective is to traverse from the upper left corner to the lower right corner and return the minimum required sum of the cell values needed to reach the destination.

In the Minimum Sum Path in a Grid Problem, each cell of the 2-dimensional grid has a value associated with it. Our objective is to traverse from the upper left to the lower right corner and return the minimum required sum of the cell values needed to reach the destination (Cormen et al., 2009; Erickson, 2019). This problem finds its implementation in navigation-related tasks such as optimizing supply chains or designing a network.

We conducted the examinations on a standardized hardware and software setup to ensure consistent and reproducible findings. The hardware consisted of an Apple M3 Max MacBook Pro with 64GB of RAM with MacOS Sequoia 15. The software environment was centered around Xcode 16 and Swift 6 for measuring algorithms' memory consumption and execution time, and R and RStudio were used for data analysis.

3. Test Cases

For the Minimum Sum Path in a Grid Problem, the test cases included various spatial configurations such as small square matrices (30x30), medium square matrices (50x50), large square matrices (100x100), rectangular matrices (50x100), boundary scenarios (30x150), and edge case performance-oriented grids (150x150).

For the Word Break problem, the test cases covered a variety of input lengths and dictionary sizes with differing distributions and lengths of words within the dictionary. They included configurations such as (60,10,500), (160,10,500), (160,20,500), (60,10,1000), (60,20,1000), (160,10,1000), (160,20,1000), (160,10,2000), (160,20,2000), (300,10,500), and (300,20,2000), where the first item represented the size of input string, second one the length of a word in the dictionary, and the third one the size of dictionary.

3.1. Solutions

In the Word Break problem with the Memoization technique, we first convert the dictionary into a set, allowing us for O(1) lookup times. Then, we define the memo, which stores the results of previously computed subproblems. Then, we define the canBreak function, which checks if a string can be segmented into words in the dictionary. Within this recursive function, we first check for a base case – if the start index equals the length of the input string, if it does, the function returns true, indicating that the input string can be segmented. Otherwise, we check if the memo already contains a computed result for the same parameters – the exact start value; in such a case, we return that value to prevent redundant recomputation. If both of these checks fail, the function enters a for-loop where it iterates over all possible end indices from start +1 to the length of the input string. For each substring, we check if it exists in the dictionary; if it does, and the recursive call to break with the end set as a startIndex also returns true, we store the obtained result in the memo and return true. If the for-loop finishes and we've not found any matching cases, we also store the result in the memo and return false.

```
func wordBreakMemoization(s: String, wordDict: [String]) -> Bool {
   let wordSet = Set(wordDict)
   var memo: [Int: Bool] = [:]

   func canBreak(_ start: Int) -> Bool {
      if start == s.count {
         return true
      }
      if let memoized = memo[start] {
         return memoized
      }
      for end in (start + 1)...s.count {
         let substring = String(s[s.index(s.startIndex, offsetBy: start)..<s.index(s.startIndex,
offsetBy: end)])
         if wordSet.contains(substring) && canBreak(end) {
            memo[start] = true
            return true
         }
      }
      memo[start] = false
      return false
   }
   return canBreak(0)
}
```

Figure 1. Solving the Word Break Problem with Memoization Technique.

In the Word Break problem with a tabulation technique, firstly, we initialize a dp table with a size equal to the size of the input string +1. By default, the table is filled with false values, except for the first value, which we set to true (an empty string can always be segmented). The function then performs an outer loop, iterating over all input indices starting from 1. For each index i, a nested loop checks all possible start indices j from 0 up to i. The function checks if the segment up to j can be segmented (if yes, then dp[j] returns true) and if the obtained substring is present in the dictionary. If both conditions are met, we set the value under the i index in the dp table to true and break out of the inner loop. The solution to the main problem is the last element of the dp table.

In the Minimum Sum Path in a Grid problem with a tabulation technique, we initialize the memo with default values of -1. The memo will store all the minimum path sums for each cell. Then we define a recursive function called dp, which calculates a minimum path sum to reach a specific cell based on the row and column. We perform checks to ensure that row and column don't extend the table's boundaries. If a value has already been computed and is present in the memo, we return it. Then, the function calculates the minimum path sum for the cell above and to the left from our current coordinates (defined by parameters passed into the function). We pick the smaller one from the obtained results, place it in the memo, and return it.

```
func wordBreakTabulation(s: String, wordDict: [String]) -> Bool {
   let wordSet = Set(wordDict)
   var dp = Array(repeating: false, count: s.count + 1)
   dp[0] = true

   for i in 1...s.count {
      for j in 0..<i {
         let substring = String(s[s.index(s.startIndex, offsetBy: j)..<s.index(s.startIndex,
offsetBy: i)])
         if dp[j] && wordSet.contains(substring) {
            dp[i] = true
            break
         }
      }
   }
   return dp[s.count]
}
```

Figure 2. Solving the Word Break Problem with Tabulation Technique.

```
func minSumPathTabulation(grid: [[Int]]) -> Int {
   guard !grid.isEmpty else { return 0 }
   let rows = grid.count
   let cols = grid[0].count
    var dp = grid
     for col in 1..<cols {
      dp[0][col] += dp[0][col - 1]
   }
   for row in 1..<rows {
      dp[row][0] += dp[row - 1][0]
   }
      for row in 1..<rows {
      for col in 1..<cols {
         dp[row][col] += min(dp[row - 1][col], dp[row][col - 1])
      }
   }
      return dp[rows - 1][cols - 1]
}
```

Figure 3. Solving the Min Sum Path Problem with Tabulation Technique.

In the Minimum Sum Path in a Grid problem with a memoization technique, we initialize our dp table as a grid copy. Then, we fill the first row and column with the values above and to the left of the cell, respectively. Subsequently, the function iterates over the cells and picks the smaller value from the cell above and to the left. The answer to the main problem is computed in the right lower corner cell.

```
func minSumPathMemoization(grid: [[Int]]) -> Int {
   guard !grid.isEmpty else { return 0 }
   let rows = grid.count
   let cols = grid[0].count
   var memo = Array(repeating: Array(repeating:-1, count: cols), count: rows)
   func dp(_ row: Int, _ col: Int) -> Int {
      if row < 0 || col < 0 {
         return Int.max
      }
      if row == 0 && col == 0 {
         return grid[0][0]
      }
      if memo[row][col] != -1 {
         return memo[row][col]
      }
      let left = dp(row, col - 1)
      let up = dp(row - 1, col)
      let minPath = grid[row][col] + min(left, up)
      memo[row][col] = minPath
      return minPath
   }
   return dp(rows - 1, cols - 1)
}
```

Figure 4. Solving the Min Sum Path Problem with Memoization Technique.

4. Results

For the Word Break problem, we meticulously selected cases that would cover various combinations of input lengths of each of the following parameters: word length, dictionary size, and size of a word in the dictionary. The cases are A: (60,10,500), B: (60,10,1000), C: (60,20,1000), D: (160,10,500), E: (160,10,1000), F: (160,20,1000), G: (160,10,2000), H: (160,20,2000), I: (300,10,500), J: (300,20,2000). Tabulation provides a more consistent execution time, showing a platykurtic distribution with fewer extreme values and distribution heavily concentrated around the mean. On the other hand, Memoization shows a leptokurtic distribution, which does not guarantee a repetitive performance due to extreme outliners. Still, it takes significantly less time to solve all cases. The execution time ranges from 0.9ms to 7.2ms (Figure 6).

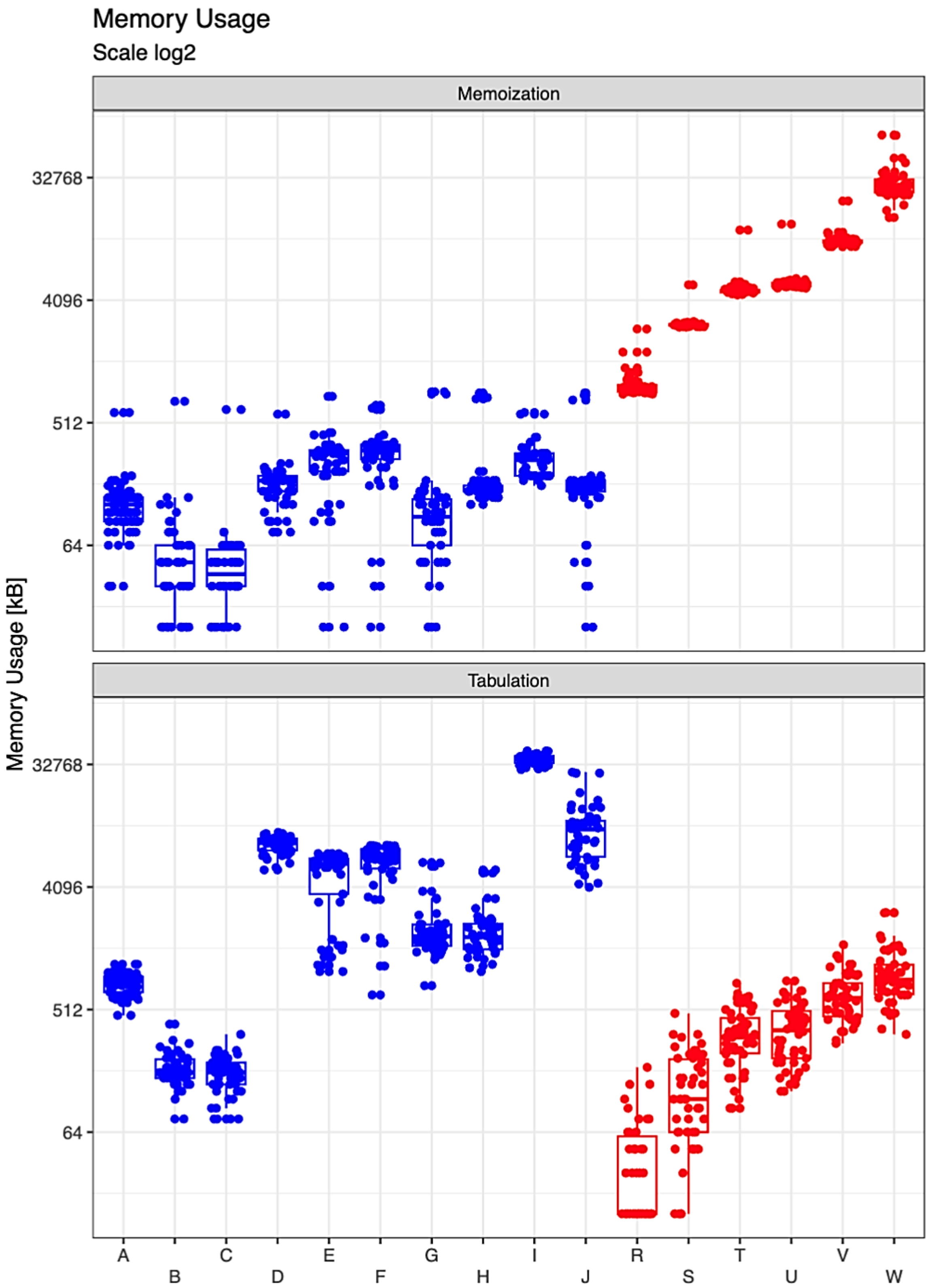

Figure 5. Memory Usage for Word Break and Min Sum Path Problems in kB.

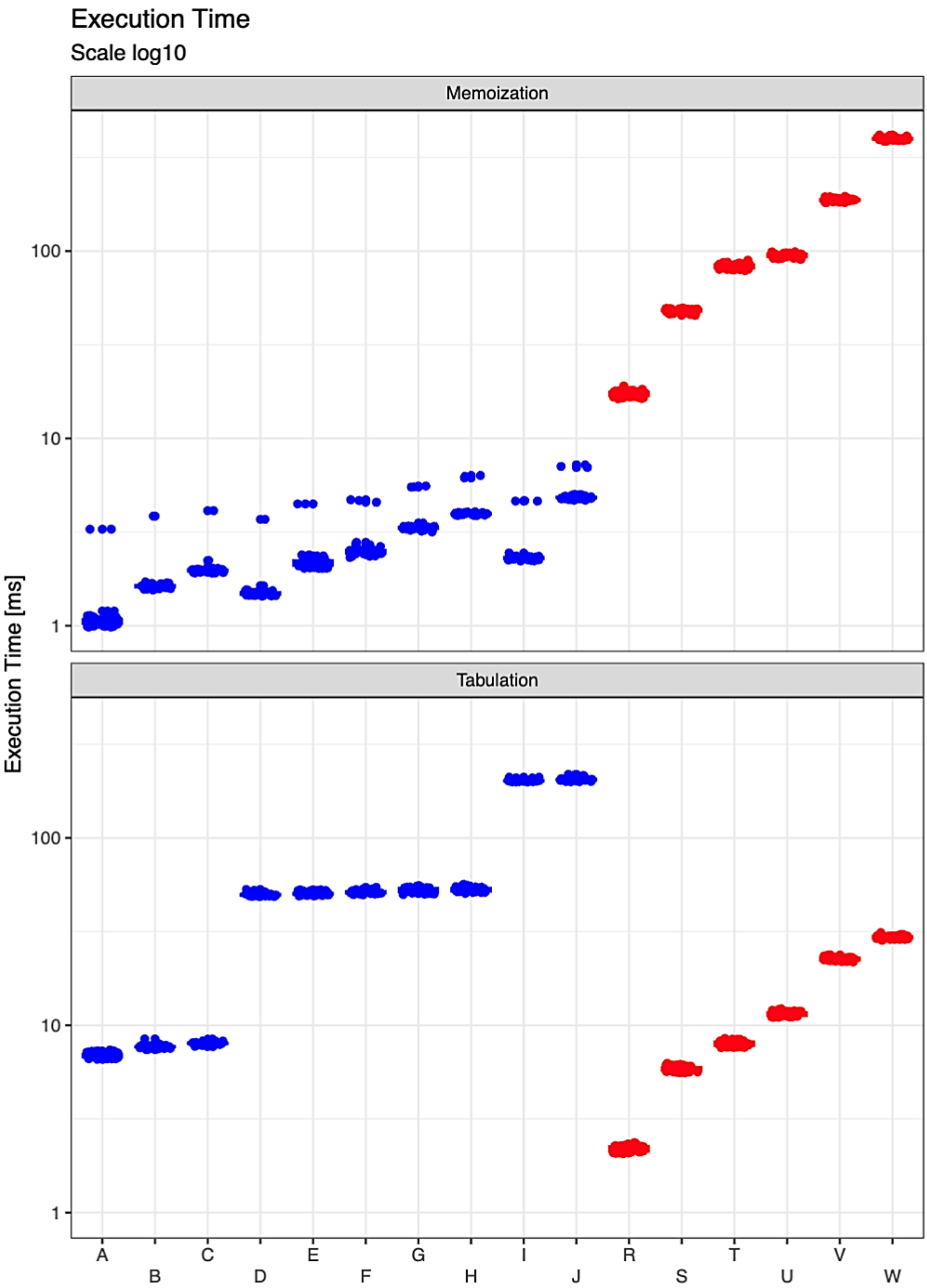

Figure 6. Execution Time for Word Break and Min Sum Path Problems in ms.

Meanwhile, Tabulation requires between 6.5ms and 218ms to compute the result (Figure 6). The increase in execution time is heavily dependent on the length of both input word and words in the dictionary. Dictionary size seems to be a lesser factor as cases with only different sizes of dictionaries score similarly. Memoization also continues its unpredictability with memory management, as it utilizes as little as 16kB and as much as 864kB when the dictionary reaches a size of 2000 (Figure 5). Despite its unpredictability, Memoization provides substantially superior memory utilization, as Tabulation uses between 80kB and 41232kB across all cases, even though stable and consistent (Figure 5). For Memoization, the main contributing factor is the dictionary size; meanwhile, Tabulation is the size of the word and words in the dictionary.

For the Minimum Sum Path in a Grid problem, we selected test cases of various grid sizes and shapes such as R: (30,30), S: (50,50), T: (30,150), U: (50,100), V: (100,100), W: (150,150). Both Tabulation and Memoization reveal an absence of extreme outliners, providing more consistent execution times. Tabulation is significantly faster across all cases, ranging from 2ms for the most minor test case (30x30) to 31ms for the most complex (150x150) (Figure 6). It takes Memoization significantly longer to complete the same instances, 16ms to 386ms, respectively (Figure 6). For both, the means grow with the grid size. Tabulation appears far more stable and resourceful in terms of memory use. Compared to Memoization, it uses 21 times less memory on average. The results range from 16kb to 2656 kB (Figure 5). Memoization has not only higher memory use but also frequent extreme outliners. The minimum usage is at 832kB, 52 times higher, and the maximum is close to 26 times higher than Tabulation (Figure 5). In both instances, there's a relation, the larger the grid, the more memory must be allocated to solve the problem.

5. Conclusions

Our findings indicate that Memoization is particularly efficient when a problem has many overlapping subproblems due to its caching mechanism. However, it generally requires more memory in complex scenarios when the ratio of overlapping to non-overlapping subproblems lowers. Despite the Tabulation being potentially slower, it offers a more consistent and efficient memory usage due to its iterative approach. That makes it a far more suitable approach for an environment with tight memory constraints.

Future work could explore some hybrid approaches or extend this comparison to other dynamic programming problems to further refine our understanding of these techniques' applications and limitations.

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OUTLINE OF THE ISSUE OF OCCUPATIONAL BURNOUT

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Purpose: The article outlines the issues related to the syndrome of occupational burnout, a common phenomenon primarily affecting professionals whose work involves contact with others.
Design/methodology/approach: The text presents definitions of occupational burnout, its symptoms and progression, and also highlights issues related to the prevention of this phenomenon.
Findings: It is important for both employees and employers to understand the phenomenon of occupational burnout in order to effectively combat or prevent it.
Practical implications: Shared responsibility and open discussions about burnout are key to creating a work environment that fosters development, well-being, and employee engagement, as well as counteracting the negative effects of this phenomenon.
Originality/value: The article organizes knowledge regarding the characteristics of and responses to occupational burnout. This is important from the perspective of employees themselves, as well as employers and lawmakers.
Keywords: job burnout, burnout prevention, occupational risk, well-being.
Category of the paper: general review.

1. Introduction

The purpose of this article is to compile existing knowledge on the syndrome of professional burnout, including its definition, characteristics, symptom progression, as well as prevention and treatment methods. A responsible approach to this issue, especially early recognition of its symptoms, is important from the perspective of both vulnerable employees, their managers or employers. Awareness of the problem of burnout enables faster identification, the implementation of preventive measures, and the adoption of strategies that can improve the quality of both professional and personal life for employees.

2. The Concept of Burnout – An Attempt at Definition

Most people have likely heard of burnout syndrome. Intuitively, we understand what this term means and how it can manifest in our bodies. It is most commonly discussed in the context of social roles tied to specific professions. In everyday understanding and across various media outlets—newspapers, radio broadcasts, television programs, websites, and social media—burnout is associated with resignation, loss of motivation, initial engagement, and sometimes feelings of despondency, meaninglessness, or physical exhaustion. In a professional context, it may also be perceived as an admission of struggling with responsibilities, lacking professionalism, or even inadequacy. For many, experiencing burnout can be an exceptionally challenging ordeal. But how is this phenomenon defined in literature? In reality, there are many definitions, as researchers in the field of professional burnout have not reached a consensus on its nature, etiology, processual character, or diagnostic tool effectiveness. Below are several classic definitions proposed by leading scholars at different stages of their work on this topic. It is important to note that the understanding of burnout has evolved over the years and will likely continue to change. Herbert Freudenberger and Geraldine Richelson define burnout as "a state of fatigue or frustration resulting from devotion to a cause, way of life, or relationship that failed to produce the expected reward" (Freudenberger, 1974; Freudenberger, Richelson, 1980, as cited in Mańkowska, 2017, p. 144). In this sense, burnout can be described as a feeling of disappointment. Christina Maslach and Susan Jackson (1981, 1984, 1986) define burnout as "a psychological syndrome of emotional exhaustion, depersonalization, and a reduced sense of personal accomplishment that can occur in individuals who work with people in a specific way". According to the researchers, depersonalization is characterized by negative, impersonal, or overly indifferent responses to others, who are typically service recipients or people under the individual's care. They describe reduced personal accomplishment as a decline in feelings of competence and success in professional work (as cited in Sęk, 2000, 2004). According to Ayala M. Pines and Elliot Aronson (1988), burnout is "a state of physical, emotional, and mental exhaustion caused by prolonged involvement in emotionally demanding situations" (as cited in Pines, 2004, p. 12). Edelwich and Brodsky (1980) emphasize the processual nature of this phenomenon, indicating that it involves growing disappointment, loss of energy, and diminishing goals. Additionally, Maslach describes "emotional overload and the subsequent emotional exhaustion as the core of the burnout syndrome. The individual becomes overly emotionally involved, overworks, and then feels overwhelmed by the emotional demands imposed on them by others" (Maslach, 1982a, p. 3, as cited in Pines, 2000, 2004, p. 37). Despite certain differences, these definitions at least provide a directional understanding of the essence of burnout.

3. Social Roles and Professional Burnout

Burnout has traditionally been examined in the context of one's profession and, therefore, in terms of specific social roles. These roles not only define a person's social standing but also require particular aptitudes, knowledge, competencies, professionalism, ethical standards, and the ability to meet the expectations of industry peers, supervisors, and society as a whole. Many years ago, Adam Sarapata (1965) noted that a profession, as a primary element of labor division, grants individuals the right to engage in socially valued activities. Within the social system, it constitutes a fundamental part of services, rights, and responsibilities—a complex of not only technical tasks but also an assigned social role. According to Sarapata, sustained professional activity shapes an individual's personality, habits, and behaviors, creating "professional families," unique lifestyles, "professional cultures", "occupational patterns and stereotypes", and "distinct professional worlds". He observed that representatives of different professions differ not only through the technical activities of their jobs but also based on their work conditions, level of education, material status, interests, consumption habits, rights, responsibilities, and roles in society (Sarapata, 1965). Thus, one's profession has a profound impact on the individual. Furthermore, it is often noted that a chosen profession can even alter a person's personality. Maslach and Jackson (1979) referenced the words of an American police officer who described this impact: "We change when we become police officers—we become brutal, tough, and cynical. You have to learn to be like that to survive in this profession. And sometimes we act this way all the time, even with our own wife and kids. But it's something you have to do because if you start to approach everything emotionally, you'll end up in an asylum" (Maslach, Jackson, 1979, as cited in Sven Max Litzke, Horst Schuh, 2007, p. 166). The influence of a profession on daily life, behavior, and even psychological well-being is clear. This applies both to social professions, in which individuals spend a lot of time with others (exposing them to conflicts, stress, and frustration, as in the cases of police officers, social workers, doctors, nurses, therapists, and teachers), as well as numerous other fields. The pressures of change and the need to adapt to new realities affect almost every profession. According to Pines (2000, 2004), people who show high commitment to their duties are particularly susceptible to burnout. She notes that burnout is a negative state linked directly to physical, emotional, and mental exhaustion, which is the final result of disappointment—a gradual process of disillusionment. It usually occurs in highly motivated individuals who work for long periods in emotionally taxing situations (Pines, 2000, 2004). Other characteristics of individuals at risk of burnout include high personal expectations, ignoring their own limits, deprioritizing personal needs and interests, and willingly taking on additional tasks (Litzke, Schuh, 2007). Below are the three main dimensions of burnout syndrome as identified by Maslach (1986, 1993), offering a perspective on this phenomenon:

1. Emotional Exhaustion: According to Maslach, emotional exhaustion results from psychological overload, fatigue caused by empathy, and engagement in daily interactions with people facing various challenges. Common signs include general fatigue, lack of energy, and diminished enthusiasm. Clinically, psychosomatic symptoms such as insomnia and headaches dominate, reflecting a phase of somatization and attempts to escape difficulties through illness.
2. Depersonalization: Also called dehumanization, distancing, or the use of "detached concern," this process makes interpersonal relationships impersonal. Those experiencing depersonalization show indifference toward others' problems (e.g., patients, clients, wards), ignore their needs, and develop strategies to minimize contact time. They may display cynicism, becoming "tough" and disillusioned. This symptom eventually manifests not only toward clients or patients but also colleagues, supervisors, or subordinates encountered daily.
3. Diminished Sense of Personal Accomplishment Maslach describes diminished personal accomplishment as a reduced sense of one's own effectiveness and a dissatisfaction with achievements, resulting from failures in coping with occupational stress (Maslach, Jackson, 1981). This dimension is characterized by a decline or complete loss of a sense of competence and the belief that one's work is ineffective and that success is unattainable. Individuals experiencing this symptom feel they lack the capacity to continue fulfilling their professional roles. During work, they may feel disappointed, frustrated, and burdened by a sense of failure and guilt, believing they are unfit for their job. This stage is accompanied by a gradual loss of energy and a sense of purpose in their work. The individual eventually starts to feel inadequate in their current position, leading to feelings of alienation, helplessness, and apathy. According to Maslach, this symptom is a direct consequence of the earlier stages and represents the most severe effect of prolonged work-related stress (as cited in Mańkowska, 2017).

Litzke and Schuh (2007) further delineate the characteristics of burnout based on earlier studies by Buchka and Hackenberg (1987) and Aronson (1983). They identify three categories of exhaustion proposed earlier by Aronson (1983):

1. Physical Exhaustion: This involves a lack of energy, chronic fatigue, weakness, increased susceptibility to accidents, neck and shoulder muscle tension, back pain, altered eating habits, weight changes, heightened vulnerability to colds and viral infections, sleep disturbances, nightmares, and increased use of medication or alcohol to alleviate physical exhaustion.
2. Emotional Exhaustion: Emotional exhaustion includes feelings of sadness, helplessness, hopelessness, uncontrollable crying, impaired emotional control, feelings of disappointment, emotional emptiness, irritability, loneliness, discouragement, and a general lack of motivation.

3. Mental Exhaustion: This category reflects negative attitudes toward oneself, work, and life, as well as a disdainful attitude toward clients, feelings of incompetence and inferiority, and severed connections with clients and colleagues.

4. Characteristics of the Burnout Process

Researchers have made numerous attempts to classify and describe the stages of burnout. The number of proposed stages varies, as does the question of whether these stages occur simultaneously, independently, or sequentially, with each stage potentially triggering subsequent stages. Jorg Fenger (2000) identifies ten stages of burnout: 1) Politeness and idealism, 2) Overwork, 3) Decreasing politeness, 4) Guilt due to declining politeness, 5) Increased effort to remain polite and reliable, 6) Lack of success, 7) Helplessness, 8) Loss of hope, 9) Exhaustion, aversion, apathy, strong opposition, anger, 10) Complete burnout, marked by self-blame, withdrawal, cynicism, sarcasm, absenteeism, somatic responses, and, in extreme cases, sudden and impulsive resignation. Matthias Burisch offers a similar yet nuanced view of this progression. He describes a series of signs and symptoms, beginning with warning signs of decreased engagement and growing fatigue. This is followed by reduced involvement across all professional functions. In the third stage, intense emotional reactions, such as depression (e.g., pessimism, loneliness, anxiety) or aggression (e.g., hostility, impulsiveness), become prominent. The fourth stage includes a weakening of basic cognitive functions and motivation, while the fifth stage features increasing psychosomatic reactions, such as issues with cardiovascular, digestive, and sexual health, as well as a heightened risk of addictions. The final stage is marked by despair and withdrawal from social and professional life, potentially leading to suicidal thoughts or actions (Burisch, 1989; as cited in Synal, Szempruch, 2017, p. 68).

Freudenberger and North (2002) delineated 12 stages of burnout development:

Phase 1: Compulsion to Prove Oneself – This stage is marked by excessive ambition and perfectionism. The employee pushes to maximize efficiency, driven by an obsessive fear of not giving more than 100%.

Phase 2: Working Harder – In this phase, the sentiments from the initial stage become exaggerated. The employee feels obligated to do everything personally and with urgency, leading to reckless task completion and reluctance to delegate.

Phase 3: Neglect of Personal Needs - Employees in this stage begin to view their difficult work situation as normal and even convenient. They downplay social needs, often regarding colleagues who prioritize such needs with disdain. Their lifestyle becomes increasingly unhealthy, and minor difficulties start to appear for the first time.

Phase 4: Displacement of Conflicts - More conflicts arise with colleagues or spouses, while issues like lack of sleep and somatic symptoms go unnoticed. Problems like missing appointments, forgetting meetings, and chronic lateness become more common.

Phase 5: Revision of Values - This phase involves a shift in priorities, leading to emotional dullness and insensitivity. Individuals become more calculating, living in the present and disregarding those who were once important to them.

Phase 6: Denial of Emerging Problems - At this stage, individuals become increasingly cynical and bitter, gradually isolating themselves from the outside world. Impatience, intolerance, and overt or covert aggression dominate their behavior. Declines in performance and physical ailments become apparent.

Phase 7: Withdrawal - Spouses, family, and friends are now seen as burdens or even enemies. Criticism from others is met with rejection and intolerance. Affected individuals report feeling disoriented and helpless, often turning to substitute pleasures (e.g., substances) for relief.

Phase 8: Significant Behavioral Changes - At this stage, individuals exhibit signs of paranoia, perceiving everything as an attack. Any additional demands at work are viewed as burdens to be quickly avoided.

Phase 9: Depersonalization - In this phase, individuals feel disconnected from themselves, viewing themselves as machines that must function. They see their lives as meaningless and overwhelming, neglecting their health.

Phase 10: Inner Emptiness - Here, individuals feel utterly depressed, empty, useless, exhausted, anxious, or panicked. Phobias and panic attacks may occur.

Phase 11: Depression This phase is marked by deep despair, self-loathing, exhaustion, and a desire not to wake up. Suicidal thoughts may arise.

Phase 12: Burnout Syndrome The final stage involves complete physical, mental, and emotional collapse, creating an urgent need for intervention (as cited in Ponocny-Seliger, 2014, pp. 2-3).

Burnout can severely impact multiple aspects of a person's life, and in extreme cases, it can endanger the health and life of the employee.

5. Burnout in the Teaching Profession

Teachers are among the professions most vulnerable to burnout, alongside doctors, nurses, social workers, therapists, and police officers. Various factors contribute to this susceptibility, including the need for close interpersonal interactions, role ambivalence (being both a friendly mentor and a strict disciplinarian), delayed gratification, student aggression, stressful encounters with parents, workplace tensions, excessive workload, and scrutiny from administrators and politicians (Sęk, 2004; Hreciński, 2016). Prolonged exposure to these stressors can lead to chronic stress and, eventually, burnout symptoms. Numerous authors, both internationally and in Poland, have highlighted how prolonged stress in teaching inevitably leads to burnout (Sęk, 2004; Hreciński, 2016; Grzegorzewska, 2006; Wołowska, 2019; Synal, Szempruch, 2017; Kirenko, Zubrzycka-Maciąg, 2011; Korczyński, 2014). Hreciński (2016), in his analysis of burnout in the teaching profession, references a popular typology by Farber (2000) on teacher burnout. According to Farber's theory, the first burnout type is the "worn-out" type. This type characterizes teachers who, in response to the demands of their work and the lack of expected results, significantly reduce their efforts. This behavior aims to mitigate the disparity between the energy invested in teaching and the outcomes achieved. Teachers in this group typically attribute the lack of results to circumstances beyond their control. According to the researcher, it may include parental indifference, lack of adequate school resources, and imposed administrative solutions that do not consider the needs of specific individuals. Educators come to believe that no matter how hard they try, they will not achieve success. The second type indicated by Farber is the frenetic type. This type is characterized by teachers who, when faced with various difficulties, do not give up but rather intensify their efforts. They make even desperate attempts and efforts to achieve pedagogical success. These are typically ambitious individuals with a strong need for achievement. This causes them to expend a large amount of energy, which over time leads to emotional or physical exhaustion. The environment, according to the researcher, notices their busyness, haste, fatigue, and the possession of inflated standards for educational and teaching work. It is difficult to convince them that failures in their teaching may stem from external factors over which they have little control. They do not accept the argument that a compromise is needed between their real capabilities at work and the goals and demands they set for themselves. While the first type of teachers (the worn-out type) gradually loses hope of achieving success, the burned-out frenetic type maintains their system of beliefs until it suddenly collapses. Another group of burned-out individuals is the underchallenged type. This includes teachers who neither show a high level of engagement in their work nor excessive fatigue, yet they are dissatisfied. The reason for this state is monotony and a lack of adequate stimulation for them. These individuals lose enthusiasm due to the boredom they experience from teaching the same material for consecutive years in the school (according to: Hreciński, 2016).

The fact that teacher burnout is a significant problem in our country is evidenced by the results of the latest nationwide study on the well-being of teachers conducted by Paliga in February and March 2023 on a sample of 7106 respondents. The surveyed indicated that the highest level of discomfort relates to the symptom of burnout, which is exhaustion, followed by a sense of lack of meaning in their work. The average level of these components in the study was 67.5% and 57.3%, respectively.

6. Counteracting Occupational Burnout

In the literature, we can find a range of activities that are part of a broad understanding of the prevention of burnout syndrome. These include expanding professional competencies, deepening knowledge, developing creative thinking skills, and cultivating interpersonal communication skills (Huget, 2015). These factors are cited as crucial for overcoming difficult situations. Additionally, researchers (Sęk, 2000; Dudek et al., 1999; Kocór, 2019) emphasize that counteracting burnout or its treatment should take into account different stages of professional careers and the perspectives of specific professional groups. Support should involve aiding employees in their development, responsible selection for the profession, a functional and effective education system, ongoing education and professional development, an appropriate motivational system for "activists" and change promoters, as well as running support groups. There is a need for special attention to be given to individuals entering the profession, who are still learning their roles. They should particularly participate in educational and training programs covering topics such as coping with ongoing stress, resolving interpersonal conflicts, and responding to and dealing with difficult behaviors from clients, patients, students, etc. For individuals directly at risk of burnout or already burned out, it is recommended to initiate intervention and therapeutic actions, with the participation of a psychiatrist, psychotherapist, or self-help groups. An important aspect of the process of recognizing, treating, and counteracting occupational burnout may be deepening self-awareness regarding personal functioning, stress-inducing factors, burnout, and its symptoms, as well as analyzing the sources of experienced difficulties and their consequences (Muchacka-Cymerman, Tomaszek, 2017). In this context, attention is also drawn to the development of professional and coping competencies that create a sense of self-efficacy, countering emotional exhaustion, and promoting better identification of one's life and professional goals, while also developing non-professional interests that provide relaxation and rest. In professions that involve helping others, it is particularly important to take care of oneself, as only such a balanced approach creates opportunities for the development of an optimal attitude characterized by detached concern (Sęk, 2005).

7. Summary

Burnout is a serious problem affecting an increasing number of individuals, especially in high-stress and demanding environments. Awareness of this syndrome and its symptoms is crucial for taking timely action—on an individual level, organizational level, and ultimately at the systemic level. Employees can implement stress management strategies, maintain a work-life balance, responsibly build their competencies, and develop healthy habits. Meanwhile, employers should invest in support programs, stress management training, and well-being and health initiatives. Shared responsibility and open discussions about burnout are key to creating a work environment that fosters development, well-being, and employee engagement, as well as counteracting the negative effects of this phenomenon.

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RESILIENCE AS AN ELEMENT OF SELF-REGULATIVE SHAPING OF METASTRATEGIC VITALITY OF ENTERPRISES

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Purpose: The reason for writing the paper is the description of self-regulation processes of enterprises in the creation and maintenance of their vitality, with which the resilience of these entities is significantly related. The purpose of the study is to show the self-regulatory (vitality-promoting) mechanisms taking place in business entities and to indicate the impact of these processes on long-term survival, for which a certain level of resilience is necessary.
Design/methodology/approach: The method used is the article is a literature analysis on the concepts of self-regulation and economic resilience. The research approach includes the description of the theoretical correlation associated with the creation of a conceptual model of the interrelationship between the phenomenon of resilience and the process of self-regulatory formation of enterprises metastrategic vitality.
Findings: In this paper the relevance of the place of resilience in the self-regulatory process forming enterprises metastrategic vitality is demonstrated.
Practical implications: The practical dimension of the considerations in the study relates to raising the level of awareness of business managers of the need to develop certain qualities and skills that must become immanent to the business entities they manage.
Originality/value: The considerations in the article, as well as the conceptual model presented in this paper, can be the basis for developing managerial skills.
Keywords: self-regulation, metastrategic vitality of enterprises, resilience of enterprises.
Category of the paper: viewpoint, conceptual paper.

1. Introduction

The socio-economic reality is dynamic if only because of the recent Covid-19 pandemic and its consequences in all systems or development of AI (Goldbach et al., 2023; Fiske, 2024; Rožman et al., 2023), climate changes (Seroka-Stolka, 2014; Paprocki, 2022) and broadly understood political changes in the world (Mamchur, Vanda, 2023; Millei, Pappalainen, 2023) – this statement is obvious, which does not change the fact that it is necessary to develop – again and again – effective scenarios for operating in this reality. The dynamics of change in the environment is particularly demanding for economic entities, which must constantly develop their mechanisms of operation in order to survive in the long term. This requires that they constantly improve their self-regulatory skills, as well as acquire the personal traits responsible for the emergence and consolidation of the ability to persist under changing conditions. The importance of self-regulation is widely discussed in world literature, mainly in the individual dimension (e.g. Angelucci et al., 2023; Guo, 2020). However, it is not only self-regulatory skills that are responsible for an economic actor's ability to survive in the long term, but also the set of traits that make up its vitality – a special and complex form of life force. The vitality, mentioned here, is metastrategic in nature, that is, it is the basis for the successful implementation of strategies for the survival and development of enterprises in the long term. It is a set of characteristics of an economic entity that allow it to maintain its dynamic functional equilibrium in the long term while pursuing goals of a strategic nature. Vitality of enterprises is connected too with their agility (Kumkale, 2022).

Among the important elements that make up the vitality of enterprises is also their resilience, also a complex characteristic by itself. In any case, all development processes of enterprises could not occur if these entities did not develop high resilience, that is, a kind of resilience to changes in the environment. However, resilience cannot be synonymous with the term resilience – it is a component of it but does not exhaust the meaning of it.

Linking the issue of enterprises resilience and the concept of the self-regulatory mechanisms' development for shaping their metastrategic vitality became the main issue addressed in this study. The issue of metastrategic vitality is discussed in the literature on the functioning of contemporary businesses. However, it is not universal. It is also common for authors of studies to analyse sub-issues, such as CSR as an element of vitality-building from a strategic perspective (e.g. Calton, 2018), or the idea of sustainability, which should be linked to vitality-building of business entities (e.g. Kuenkel, 2019). To the set of partial factors that create metastrategic vitality, employee vitality without a doubt should be added because it can be assumed that a vitality of human capital is the base of every activity of enterprises.

The aim of this reflection is therefore to present the interconnections between phenomena such as resilience, self-regulation, the functional development of economic actors (mainly businesses), their long-term survival and the vitality of these actors that allows them to achieve their strategic goals in the long term. Such a broad spectrum of linkages is difficult to find in the existing literature on the subject.

The basis for this study is the author's concept of the self-regulatory formation of enterprises' market behaviour, which refers directly to the functional development of enterprises and the mechanisms for generating their market behaviour based on a creative approach to the long-term implementation of goals of a strategic nature in the context of the personal characteristics of economic agents necessary for this development – their vitality (Majecka, Letkiewicz, 2020).

2. Resilience as a feature of the mechanism of business operation

Resilience, like self-regulation, are widely defined by a variety of sciences and conceptual approaches. In the literature, one can find concepts based on the consideration of self-regulation and resilience as personal traits – for example, one can consider the problem of resilience and self-regulatory abilities of soldiers, migrants, and managers experiencing obstacles, often of a cross-cultural nature, in their career development (Artuch-Garde et al., 2017). One can also address the issue of self-regulation and resilience, the development of which is a way to improve the situation of youths being at-risk (Rothstein et al., 2016). Yet another concept focuses on resilience as an essential competency for managers in the manufacturing industry (Nan, Kanokporn, 2023). However, both concepts can also be applied to the activities of enterprises, as a whole, by pointing out the mechanisms of subjective self-regulation in them, as well as describing their resilience. In the most general terms, the concept of economic resilience (i.e., related to economic entities) is usually associated with some kind of strategy for coping with a crisis situation and skilfully responding to situations of discontinuity and turbulence (Piórkowska, 2015). This enterprise strategy can and should be based on creativity or even improvisation (Lloyd-Smith, 2020). It is still worth mentioning that resilience can be simultaneously viewed as a process of coping with difficult external circumstances and as a result of previously taken countermeasures (Melián-Alzola, 2020). Resilience of various entities (because not only enterprises, but also other types of organizations – not commercial, but economic such as various associations and foundations that conduct business activities without being enterprises, cities or supply chains) is a fundamental competence of efficient response to changes that can significantly disrupt the processes of achieving goals without falling into long-term states of crisis. In the case of strictly economic resilience, it should include productivity, safety and agility (Banaszyk et al., 2021). Productivity classically understood as the ratio of goods produced and sold to the assets consumed in the process – is not enough to define an entity as a residual, it is a measure overly geared only to multiply capital for its owners. A resilient enterprise must at the same time guarantee security, in this case understood primarily as a job protection in a corporate crisis. Agility, on the other hand, in relation to a resilient enterprise, means primarily being close to the market and the customers, interacting efficiently with suppliers, having flexible operational capabilities and strategic leadership (Banaszyk, 2022).

Components of resilience in a different perspective (Majchrzak, 2020) constitute: strategic revitalization, flexibility and resilience. Strategic revitalization should be understood as the ability to make a strategic changes (Floyd, Lane, 2000), flexibility as the ability of a company to adapt to its environment (Krupski, 2008) and resilience, which is the ability of an enterprise to return to the state prior to the occurrence of a disruptive factor in its operations (Bishop, Hydoski, 2010). The resilience characteristic of the company allows it to reactively tackle a difficult situation, but also to be proactive, understood as developing by taking up challenges based on learning processes (Seroka-Stolka, 2017).

With resilience defined in this way, it is evident that it is co-responsible for, firstly, providing a sustainable mechanism to ensure the firm's ability to return to its pre-disruptive state and, secondly, for ensuring a sustainable capacity for strategic revitalisation, consisting of the ability to adapt to sustained (albeit unstable), long-term changes in the economic agent's environment. The first dimension boils down to the ability to compensate for changes that reduce the efficiency of the achievement of objectives, occurring in the environment, through changes in the mechanism of functioning, based on regulators (rules for the performance of specific functions), i.e. self-regulation. The second, the long-term – the strategic dimension of regulatory resilience boils down to the ability to create a mechanism to operate in a way that is not present in the environment, i.e. the ability to change and induce changes in the environment in the direction desired by the company, e.g. by creating demand or changing the formal and legal conditions of business (lobbying). Both activities lead to the ability to build a state of functional homeostasis (dynamic equilibrium) of the company, in which resilience is a permanent feature of the company, inherent in the mechanism of its functioning.

The question of the dynamic functional equilibrium (homeostasis) achieved by enterprises in the process of their development is one of the basic skills of these entities. This skill is particularly necessary in the context of shaping and assessing the behaviour of economic systems in socio-economic systems. The pursuit of a state of functional homeostasis, as a goal of regulation, requires companies to construct analysis and monitoring tools for both state measurement and dynamic analysis. In the long term, the need to restore the equilibrium of systems and the partial equilibriums of subsystems is caused by disturbances (both of an external and internal nature) that require transformations in the economic actors. These transformations are mainly caused by processes in the environment that are independent of the company, triggered by actors generating regulatory rules that are relevant to the market in question (this includes actors that are regulators by nature, such as the state, but also other economic actors). The analysis of changes over time, i.e. the analysis of dynamics, is important from the point of view of the functional development of economic agents. By applying the tools of monitoring and analysis within the spatio-temporal continuum, it is possible to make a comprehensive diagnosis of the economic entity, which makes it possible to describe the functional efficiency and effectiveness of the economy and to determine the state of the economic entity in the context of its development possibilities (Majecka, Letkiewicz, 2020).

The construction of development scenarios by enterprises takes into account the nature of the market as a space-time for the functioning of the demand-supply-price mechanism, in which all processes are dynamic. This is because one of the basic characteristics of the phenomena taking place in socio-economic reality, and above all of changes (including developmental ones), is their temporal orientation. As time goes by, the company will achieve increasing efficiency by pursuing successive – primarily growth-oriented – stages of its life cycle

(Majecka, 2015). From the point of view of a functional-temporal orientation, the concept of evolution in terms of the ability to shape the mechanisms and functional skills of enterprises, which these entities must acquire with the succession of their life phases, reflecting the progression of the functional development of these entities, appears useful (Fryca-Knop, 2014). The concept of the functional development process includes four basic phases (Szałucki, 2007):

- regulation,
- adaptation,
- optimisation,
- strategy.

The enterprises' attainment of the various stages in the life cycle is closely linked to the development of the functional skills of these entities specific to each phase and, therefore, to their varying levels of resilience. The processes of change during the various phases of the enterprises' life cycle are subject to all the resources necessary to achieve the objectives of these entities. Particularly important among them are human resources because their 'quality', as one of many components, determines the functional-regulatory efficiency of an enterprise, its competitive strength and the building of resilience. The building of functional-regulatory efficiency and, consequently, the shaping of the resilience characteristic, requires companies to recognise a number of regulators that fundamentally affect their activities, being the basis for the construction of internal regulators and being qualitatively different for the different phases of the life cycle of the various entities (Majecka, Letkiewicz, 2020).

The ability to build the agility of functional processes, as well as the ability to take effective adaptive action and, at higher stages of development, optimisation or strategic action, must derive from the self-regulatory skills of the entity in question. The ability to self-regulate in the different phases of functional development of economic systems is based on its fundamental form inherent in the regulation phase, i.e. it consists of the ability to identify, interpret and actively, tailored to the needs of the entity, implement changes in the environment (Letkiewicz, 2013). With functional development, this process acquires the characteristics of higher efficiency, which makes it possible to distinguish the qualitatively different self-regulation inherent in the adaptation, optimisation and strategy phases (Majecka, Letkiewicz, 2020). The place of self-regulation in functional development processes is shown in Figure 1.

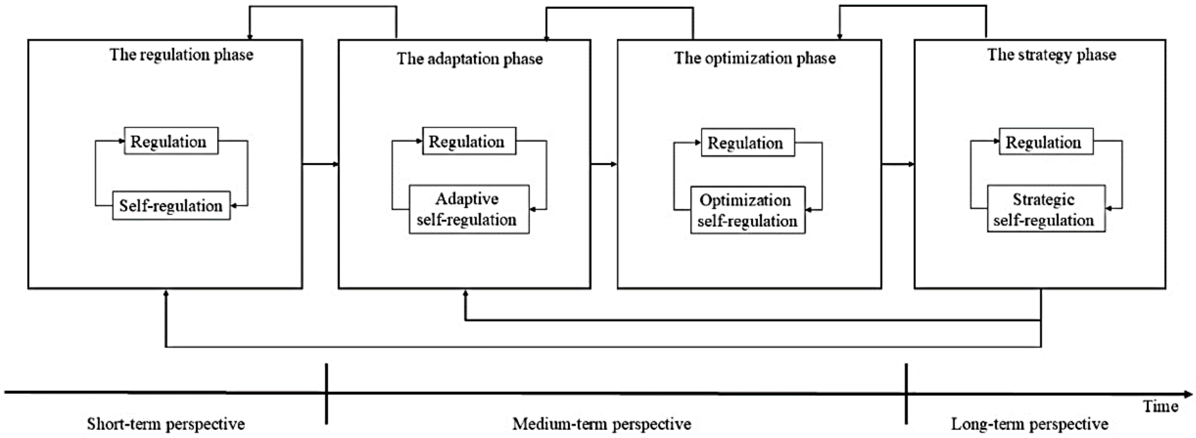

Figure 1. Self-regulation in the perspective of functional development of economic systems.
Source: Majecka, Letkiewicz, 2020.

It is extremely difficult to measure precisely the level of homeostasis of a company, as the determinants and consequences of this phenomenon extend far beyond the company. However, it is possible to refer to certain achievements of a company that manages to move towards homeostatic development. These achievements in turn are measurable, e.g. the efficiency of resource use, i.e. the efficiency of management or, at the strategic level, the volume of pollutants emitted into the environment or the level of social responsibility of the enterprise (Majecka, Letkiewicz, 2020). However, the fundamental aspects of homeostatic development, and therefore of resilience, flow directly from its functional characteristics and, above all, from its ability to inscribe in regulators the capacity to learn and the capacity to restore functional fitness when this fitness is compromised by mismanagement and/or changes in the environment.

3. Self-regulatory resilience of companies

In the economic context, it can be considered that an important feature of the entity's existence in the long term is continuity, stability, constancy, defectlessness (Majecka, Letkiewicz, 2020). Referring to the conditions of sustainability of enterprises, it should be stated that a permanently existing enterprise should be efficient in its entirety and in individual functional areas, as all partial dimensions of efficiency form the subject systemic efficiency. This state enables the realisation of medium- and short-term objectives through adaptation and optimisation and, consequently, building conditions for strategic development consisting in the best configuration of partial objectives in the given economic conditions, but with a strategic dimension. The functional outcome of the sustainability of economic agents, understood in this way, is their vitality perceived as a capacity for survival (a kind of life force), allowing for self-regulation (in this context, the self-adaptation of the agent to changes in the environment without external coercion). It is, therefore, the ability to sustainably search for and exploit existing in the environment and perceived opportunities to improve the subject's condition while compensating for its weaknesses (Fryca-Knop et al., 2017).

Every economic system, while trying to achieve the main objective, which relates to the entity, as a whole, simultaneously pursues a bundle of sub-objectives. The range and variety of objectives (Figure 2) to be pursued in parallel is conditioned by resource constraints and the divergence of internal interests as well as the organisation's environment. Self-regulation quite often forces difficult choices to be made between mutually exclusive sub-objectives, leading to the choice of the optimal solution – or at least this choice should be the optimal one – the best one under the given conditions. The bundle of objectives of an economic system is determined by the interaction of a group of exogenous as well as endogenous factors. The effect in the form of the final bundle of objectives, its composition and structure depend on many factors, but mainly on the object of the enterprise in question and the role it has to play in relation to its own members and the environment.

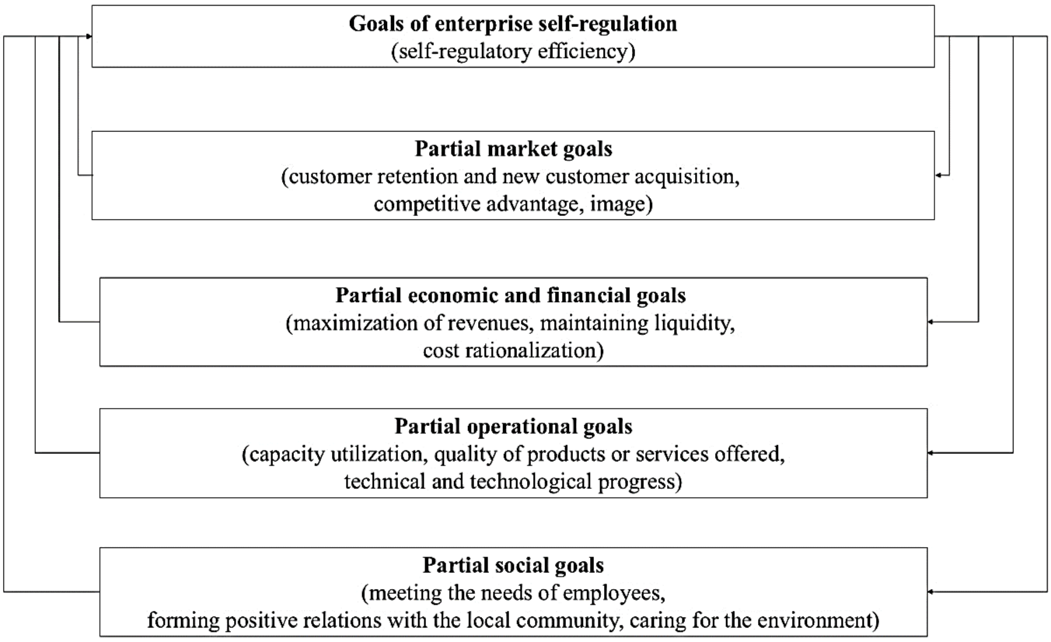

Figure 2. Diversity of sub-goals of self-regulation.

Source: Majecka, Letkiewicz, 2020.

The bundle of partial objectives of self-regulation constructed in this way creates the conditions for metastrategic vitality, of which resilience is a part and at the same time a condition for the development of enterprises as a whole. Resilience also has a somewhat partial character here and is responsible for the processes of revitalisation, adaptation to changes in the environment and the resilience of the structures of the economic entity in the individual functional areas. Metastrategic vitality based on resilience is embedded in external and internal conditions and, taking on different forms (dimensions), also differentiates itself in individual functional areas corresponding to groups of sub-goals. Consequently, it creates the basis for the sub-goals of self-regulatory vitality formation. The determinants of self-regulatory metastrategic vitality formation therefore include the determinants of self-regulation:

- operational – technical and technological development, resource market and human capital,
- economic-financial – risk, taxes, cost of capital,
- work – social system, labour market, individual self-regulation,
- marketing – goods/services market, competitors, buyers.

Operational self-regulation should consist of seeking the best configuration of resources and processes under the given conditions. Most often, within the framework of self-regulation, the criterion for optimisation is the principle of minimising production costs at a given volume of effects and time caesura. The improvement of the production process may be focused on the processes themselves or the results, the outcomes of these processes (e.g. products, services) and may take an active form (it may be realised during the process) or a passive form (after the realisation of the process). It can also take the form of proactive (anticipatory) or reactive actions (as a result of, for example, complaints sent by customers) in the area of the quality of the process, its duration or costs. Actions taken to improve production processes bring measurable effects, not only in terms of efficiency, but also in economic and financial terms. They can result in the reduction and optimisation of inventories, improved quality of work, increased efficiency and productivity, improved communication and improved effectiveness and efficiency of operations (Knop, Mielczarek, 2015). Hence, a group of areas that are affected by the self-regulatory shaping of strategic vitality emerge. In the operational sphere, these are productive employment, resource flows and productive assets. As a consequence of the self-regulatory shaping of metastrategic vitality, the bundle of objectives takes the form of labour productivity, asset productivity and synergy building.

Self-regulation in the economic and financial sphere of economic agents is conditioned by external regulators of economics arising from the socio-economic system and internal factors referring to the specifics of economics in a particular field or sphere. The determinants of the socio-economic system boil down to the economic policy implemented by the state, in particular the parameters of macroeconomic policy (interest rates, exchange rates, taxes, duties, price regulation). In addition, they result from the activities of other market participants in the form of capital donors (investors and banks operating in the financial market) and other economic agents (customers, competitors). Hence, the main determinants of economic-financial self-regulation include risk, taxes and the cost of capital, while the dimensions of self-regulatory action in enterprises concern assets (fixed and current), capital (own and third-party) and working capital (current assets and short-term third-party capital). Targets, on the other hand, depending on the time horizon, can take the form of liquidity, profitability of sales and return on capital.

The increasing integration of economic actors into the social determinants of sustainable development is leading to an increased awareness of the value of human beings and their involvement in the management process. Fundamental changes are taking place in work processes and their importance for individuals and social groups. The value of human resources and the ability to bring workers and economic agents into harmony is one of the fundamental issues of functional sustainability and becomes the basis for building internal regulators correlated with external conditions of functioning. At the centre of this phenomenon is a human being/employee who simultaneously appears in several roles – on the one hand as a subject of achieving the objectives of the economic agents, on the other hand as a subject of achieving one's own objectives, and on the third hand as a subject of socio-public-legal processes, including those of a market nature, manifested especially on the labour market (Letkiewicz, 2013). The factors indicated above are determinants of self-regulation in the sphere of work and take the form of the social system, the labour market and individual self-regulation. Consequently, its dimensions relate to employment, the work system and the incentive system, and its objectives include labour flexibility, welfare and well-being of workers.

Slightly different from the dimensions of self-regulatory metastrategic vitality formation, described so far, as it is the most coupled to the environment, is the market dimension exemplified in activities of a marketing nature. Self-regulatory adaptive changes will be effective when they ensure that the company gains and maintains an appropriate level of competitive advantage (Andruszkiewicz, 2015), and consequently a proper market position. This cannot be achieved without considering the external perspective as the most important, although self-regulation still focuses on the internal processes of the economic entity. Nowadays, economic systems (enterprises created to fulfil the objectives of their owners) achieve the effectiveness of their defined marketing objectives (market position and competitive advantage) by engaging in identifying the needs of customers and then adapting their products/services/goods to meet the expectations of buyers more effectively than the competition. The increase in competition means that the focal point of any economic system is the process of producing and offering the customer what he or she expects, so there should be a systemic focus of all activities in these entities aimed at creating value for the customer. The marketing sphere becomes the basis for market success, based on analysis, planning and implementation of solutions within the framework of establishing market objectives, defining the needs of current and potential customers, market research and influencing the market through coordinated marketing tools (Przedsiębiorstwo…, 2016). Thus, the determinants of self-regulation in this area are the market for goods and services and its mechanisms, and there are also competitors and buyers. The dimensions of self-regulatory action become the ability to meet needs, market potential and marketing potential, with the objectives of competitiveness, sales effectiveness and image.

4. Metastrategic vitality versus corporate resilience – a model-based approach

At the core of the self-regulatory processes of each entity, both in a partial and a holistic dimension, as well as the self-regulatory formation of market behaviour and – as a result – the corresponding stratification position of the economic entity, lies its vitality. Vitality is a kind of ability to take a proactive approach to improve the state of the organisation, as well as the constant search for ways to do so (Brzeziński, 2009), which makes it possible to compensate for the entity's weaknesses. Vitality is a complex of various partial characteristics of the economic entity, which, existing in a kind of equilibrium of a dynamic nature, enable this entity to be flexible and adapt to the changing conditions of its functioning (Majecka, 2013). It is evident here that a vital enterprise is also a resilient enterprise. Thus, economic agents, in generating behaviour that is acceptable in the socio-economic system and beneficial to themselves, must constantly develop self-regulatory skills – this is due to the vitality of the subject, but also shapes this vitality. There is a feedback loop, in this case concerning the interrelationship between the self-regulatory skills and their expected effect of occupying an appropriate market position in an attractive stratum of other actors and the vitality of the economic actor. As a consequence of these couplings, a new level of vitality emerges (which can be referred to as metastrategic vitality), which, being a set of constantly improved mechanisms of the economic agent, allows it to achieve its intended position in a market characterised by the 'new normal', becoming at the same time the result of its self-regulatory activity and the corresponding level of resilience inherent in it (Figure 3).

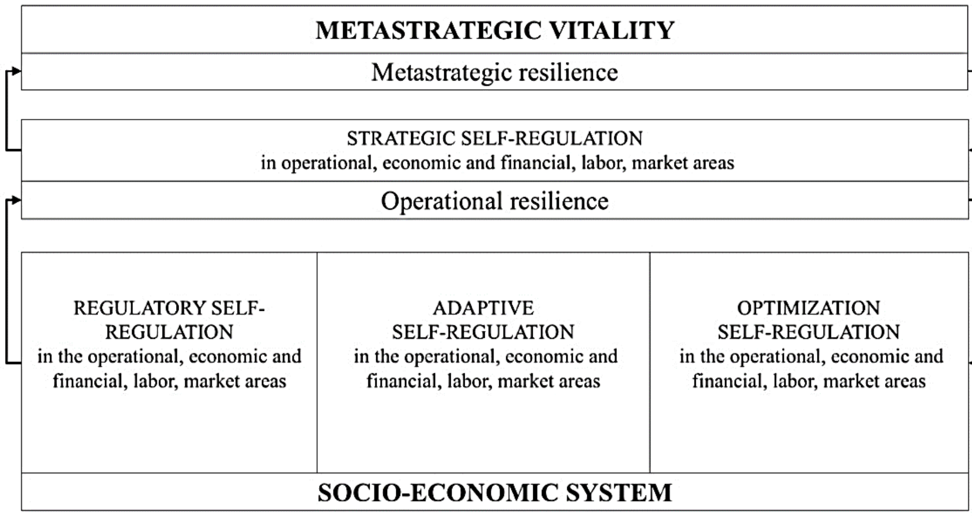

Figure 3. Modeling metastrategic vitality and metastrategic resilience.

Source: own study.

In linking the phenomena of self-regulation, metastrategic vitality and the resilience of the economic entity, it should be noted that resilience appears in two forms. The first, operational, is the result of self-regulatory interactions of a fundamental nature. Metastrategic residuality, on the other hand, appears at a higher stage of the functional development of the enterprise and is linked to metastrategic vitality. This means that the characteristics of the residualisation phenomenon are not one-dimensional and stratify according to the stage of development of the economic entity. Functional development, therefore, requires the continuous improvement of the entity in terms of its resilience. On the other hand, an increasingly higher level of residualisation makes it possible to pursue increasingly ambitious market objectives and is a kind of guarantee of the entity's survival in the long term.

Self-regulatory activity and metastrategic vitality and the associated resilience depend on the degree of functional development of the enterprise and the possession of certain success factors. Thus, in achieving better resilience within the framework of metastrategic vitality, economic agents should, through self-regulation, combining the scale of activity with its flexibility, aim to build the following features of the process (Penc, 2008):

- speed – associated with responsiveness (timely) to changing buyer needs,
- consistency – related to the reliability of satisfying the needs of buyers,
- acuity of perception of the competitive environment – connected with the ability to anticipate market changes (both in terms of the needs and expectations of buyers and the behaviour of competitors),
- agility – associated with the ability to respond to changing expectations of the company's stakeholders,
- innovation – related to the ability to create new value (in terms of technology, the way and character of work, the way of servicing buyers or market behaviours).

If an economic entity is able to creatively confront changes in the market with its self-regulatory competences and to shape its resilience accordingly, it is likely to be successful. As a rule, success is considered to be the domain of the market leader (also in the sense of a leadership position in a sector or a specific field of activity), as this is how the so-called positional approach to organisational strategy defines the market position of an enterprise (Obłój, 2004). Consideration of the self-regulatory context of metastrategic vitality formation and, within this, the resilience of economic actors indicates, however, that there are specific ways of achieving success also for actors who are not leaders (although one should be aware that certain obstacles stand in the way of these success strategies).

The types of success (which at the same time determine the ways of seeking efficient self-regulation and sustainability), together with the obstacles to achieve them, can be presented as follows (Penc, 2008):

- success through quality – a company without good quality products/services/goods is not able to be present on the market in the long term; it is constrained by the fact that competitors offer ways of satisfying buyers' needs at a similar quality level,

- success through top-quality service – top-quality service means, first and foremost, a personalised approach to the needs of the purchaser, as each purchaser has his or her own way of relating to a particular parameter of good service and what he or she may expect from the company in a different way,
- success through lower prices – a low price alone is not enough, it must be combined with good quality and good service to bring the company closer to success,
- success through high market share – companies achieve this type of success if they are able to fully exploit the economies of scale of their operations – while a significant market share alone is not enough,
- success through adaptation and adjustment to the individual requirements of the purchaser – it is not only individualised service that serves the success of a company, but also an individualised product or service that meets the specific needs of the purchasers,
- success through continuous improvement of the business object – improvement is the basis for success as far as successive improvements are accepted by customers,
- success through innovation – innovation puts the company ahead of the competition, but it is the kind of success that requires a lot of money from the company and a high degree of risk tolerance,
- success by entering fast-growing markets – in fast-growing markets only those companies that are able to keep up with change very quickly will be successful,
- success by exceeding buyers' expectations – the basis of a company's success may also be the anticipation of buyers' needs and expectations – the company that not only fully meets the needs, but is able to anticipate their changes – wins, but at the same time should be aware that this cannot be a one-off act (buyers may expect continuous surprise and anticipation of their expectations).

A certain type and level of resilience is inherent in each type of success, which underpins the ability of an economic entity to survive in the long term. Success, in the metastrategic sense – survival in the long term – cannot be achieved without adequate skills to revitalise the entity, flexibility to adapt to conditions, and resilience to internal disturbances and environmental turbulence.

5. Discussion and conclusions

There is no doubt that today's dynamic economy circumstances cause a number of enterprises' organizational behaviours as a reaction to these changes. This activities as a goal have a levelling of negative trends and giving a chance to get a success, defined as the ability to respond appropriately to the changes in the long term – metastrategic vitality. Separated, partial analysis the enterprise vitality combined with CSR or sustainable development, or human capital vitality gives a partial perspective related to the activities of entities in this field. Mentioned areas, from the point of view presented in the article, are the areas of enterprises' self-regulation but it can be assumed, without a doubt, that a vitality of human capital is a success condition of them. This statement is based on the fact that among the results of research on the vitality of enterprises are available research results that show that human capital is crucial for long-term organizational success (Marinova et al., 2018) and that to survive chaotic conditions, contemporary organizations demand innovation and increasing a competitiveness (Hsiung, 2012), which is highly dependent on employees' positive behaviour. Therefore, employees' proactive vitality management is adopted as an important forecaster of usage and support of organizational resources to creating their vitality (Khan et al., 2023) but from the point of view adopted in this publication important was identification a systemic interconnections between phenomena such as resilience, self-regulation, the functional development of economic actors (mainly businesses), their long-term survival and the vitality of these actors that allows them to achieve their strategic goals in the long term. This led us to the conclusion that development processes, including the building of resilience, of enterprises are extremely complex from the perspective of enterprises, as they are the sum of small self-regulatory changes, improving the mechanism of functioning, while at the same time requiring fundamental changes, permanently altering this mechanism. These processes are embedded in the spatio-temporal continuum of the economic entity manifested in the short, medium and long term perceptions of changes and trends (including megatrends) in the environment and the different, dependent on the perspective adopted, set of actors (stakeholders) and their different causal role in building homeostasis. In the short term, building short-term resilience is based on self-regulation of a regulatory and adaptive nature. The former type of self-regulation relies on the ability to implement regulators of a legislative nature, the source of which is the system of laws in force. The second type of self-regulation involves acquiring the ability to measure and assess performance, which is fundamental to this type of self-regulation, in order to implement market regulations based on awareness of the basic regularities of market functioning, i.e. the market mechanism.

A higher level of functional development is the level of building operational resilience at the level of adaptive and optimising self-regulation. Self-regulation based on adaptive processes is based on the recognition of regulators of the behaviour of entities in the market and the identification and implementation of more efficient regulators responsible for this type of behaviour than those existing in the entity. A medium perspective on building resilience is optimisation self-regulation, based on the ability to identify more efficient regulators, to predict and calculate the results of their implementation and the ability to choose the mechanism and thus the best behaviour under the given conditions.

The highest level of resilience is metastrategic resilience based on strategic self-regulation, the basic feature of which is the ability to shape changes in the environment that are expected by the economic entity. This may involve creating market needs, e.g. by introducing new products or services to the market or influencing regulations, thereby creating new conditions in the socio-economic system. Consequently, the highest level of resilience is metastrategic resilience, which determines vitality at this level. This vitality is based on megatrends occurring in the socio-economic system referring to long-term changes of a civilisational nature.

The process of building self-regulatory fitness at different stages of functional development and acquiring operational and metastrategic resilience is a process of continuous learning and improvement of the mechanism of functioning and building new conditions of homeostasis. It is interspersed with successes and failures increasing or decreasing functional performance. However, the condition for successive development is the awareness of the economic entity as to the type and strength of the residual – functional inertia or the strength of the sustainability of being, so as to make rational decisions conditioned by their positive or negative effects in terms of the greatest possible predictability. It is also important to remember that some phenomena cannot be predicted (Taleb, 2020; Millkey, 2009) and only metastrategic vitality and resilience will allow enterprises to survive.

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EUROPEAN PERSPECTIVE ON DIGITAL INDUSTRIAL SYMBIOSIS

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Purpose: The aim of the paper is to assess the current situation in European countries with regard to their needs for the implementation of Digital Industrial Symbiosis (DIS). It is also an identification of the ongoing European Commission projects that support the development of DIS.
Design/methodology/approach: The study employed secondary sources of information, including reliable websites, to analyze industrial symbiosis implementation across various European countries. Case studies of EU countries were selected based on their innovation levels as per the European Innovation Scoreboard. Unstructured interviews with representatives from several organizations, and review of several EU funded projects enabled to identify barriers and challenges to Digital Industrial Symbiosis development.
Findings: The study made it possible to assess the development of industrial symbiosis in selected European countries and their openness to implementing the concept of Digital Industrial Symbiosis. The role of EU programs in this process was also considered.
Research implications: The review can become the basis for exploring opportunities for international cooperation in the development of DIS platforms and for defining research guidelines in this area in the context of circular economy advancement.
Practical implications: Digital Industrial Symbiosis fosters cross-sector collaboration between industry, academia and policy makers, driving innovation and the creation of new business models, as well as supporting the EU's sustainability goals. Therefore, capacity building through EU-funded projects and policy development that ensures the integration of Industrial Symbiosis into standardization processes is crucial to equip entrepreneurs, SMEs and professionals with essential skills and digital tools to implement DIS.
Originality/value: The article presents a new concept for integrating stakeholder activities toward a circular economy - through Digital Industrial Symbiosis. Using mini case studies of European countries and EU projects, a broad European perspective on DIS challenges and needs is gained.
Keywords: industrial symbiosis, digitalization, Europe, European Commission programs.
Category of the paper: general review, case study.

1. Introduction

The concept of the circular economy, defined as an economic system that eliminates waste by reducing, reusing, and recycling products and materials, is gaining momentum among academics and policymakers (Lewicka et al., 2023). At the micro-level, companies can contribute to the circular economy by adopting innovative business models that focus on sharing resources, collaborating with stakeholders, and implementing cleaner production processes. Thus, the circular economy involves cooperation between actors in industrial networks, fostering symbiotic relationships that bring economic, social and environmental benefits (Lewicka, Zakrzewska-Bielawska, 2016).

Therefore, a key concept within the circular economy is Industrial Symbiosis (IS), which involves the collective use of under-used assets such as machinery, vehicles and storage space between companies, and the exchange of residual outputs such as materials, by-products and energy (Chertow, 2007; Ventura et al., 2023). This process benefits from the geographical proximity of companies, often located in eco-industrial parks and clusters, which enables the creation of a pro-environmental “innovation climate”" conducive to eco-innovation dynamics.

Nowadays, digitalization offers new opportunities to enhance IS, such as information and communication technologies (ICT) that enable monitoring and tracking material and energy flows through manufacturing processes. Digital Industrial Symbiosis (DIS) can lead to potential synergies by facilitating real-time information exchange between stakeholders. However, a lack of key IS-related services, low awareness of the availability of such solutions and insufficient involvement of potential users has limited the success of DIS (Kosmol, Leyh, 2021). Only limited research is being conducted to understand how digital technologies can help overcome barriers to the development of IS.

The European Commission has played an important role in promoting the circular economy through policies and action plans, and its influence can be crucial in making the DIS a reality. For example, the new 2020 Action Plan for a Cleaner, More Competitive Europe (CE Action Plan, 2020), which emphasizes sustainable product design and circularity in production across key value chains such as electronics, ICT and plastics, can also be a catalyst for advancing the Digital Industrial Symbiosis.

The main objective of this paper is to assess the current situation in European countries with regard to their needs for the implementation of Digital Industrial Symbiosis. It is also an identification of the ongoing European Commission projects that support the development of Digital Industrial Symbiosis.

2. The concept of Digital Industrial Symbiosis

The Industrial Symbiosis is a collaborative approach concerning physical exchange of materials, energy, and services among different firms: accordingly, wastes produced by a given firm are exploited as inputs by other firms. This methodology is able to generate remarkable environmental benefits, since it allows to reduce the amount of wastes disposed of in the landfill and the amount of primary inputs used by the industrial sector (Albino, Fraccascia, 2015).

Many technical solutions for waste and by-product material, water, and energy reuse between neighboring industries (so-called synergies) have been discovered and applied in the IS examples from all over the world (Akyazi et al., 2023). However, the potential for uptake of new synergies in the regions is often limited by a range of non-technical barriers (Krom et al., 2022). The latter include environmental regulation, lack of cooperation and trust between industries, economic barriers, and lack of information sharing (Lewicka et al., 2023). In addition, the growing complexity of the industrial processes and the pressing need for sustainable resource management require now a fast transition to a new Digital Industrial Symbiosis paradigm, by leveraging the unprecedented capabilities of digital technologies for tracking, analysing, and optimizing the flow of materials and energy across different industries, thus facilitating more effective symbiosis (Kosmol, Leyh, 2021).

Several definitions of IS exist, highlighting its complexity and diverse applications. According to Chertow (2007) the essence of IS lies in the exchange of resources between at least three different entities not primarily engaged in recycling. Lombardi and Laybourn (2012) described IS as a network fostering eco-innovation and long-term cultural change without requiring geographic proximity. Other authors framed IS within the context of transforming industrial systems into ecosystems through closed-loop thinking and material exchanges, requiring a collective approach and diverse organizational involvement (Mallawaarachchi et al., 2020).

As a response for the challenges of Industry 4.0 (Ventura et al., 2023), Digital Industrial Symbiosis (DIS) refers to collaborative and mutually profitable relationships between different industries and/or sectors to improve resource utilization and productivity based on business opportunities through digital platforms. It creates an interconnected industrial landscape where one company or sector uses underutilized resources such as: as waste, by-products, residues, energy, water, infrastructures, capacity, expertise, equipment, materials from another company or sector with the result of keeping resources in productive use for longer and for an economic profit (Scafà et al., 2020).

Despite the widely acknowledged benefits of IS, such as cheaper prices, job development, and less waste and pollution, its practical use has been restricted. Barriers include firms' commitments to sustainability, current environmental rules, community awareness, and a lack of trust in industry collaboration. It may be assumed that digitalization will lead to the elimination of at least some communication barriers (Krom et al., 2022; Iyer, Sangwan, 2024).

Digital platforms can support IS by functioning as management tools and marketplaces for trading industrial waste and by-products, and ensure data confidentiality to alleviate concerns about sharing sensitive information (Krom et al., 2022).

Selected European countries are at varying stages of development in the field of industrial symbiosis. Particularly, Digital Industrial Symbiosis is being gradually, yet unevenly, advanced across EU nations (Järvenpää et al., 2021; Proszowska et al., 2023).

One of the most recognized examples of industrial symbiosis in practice is Kalundborg Symbiosis – a collaboration between nine public and private companies in Kalundborg, Denmark, established in 1972 (Kalundborg Symbiosis, 2024). It represents the world's first industrial symbiosis, utilizing a circular production approach. The core principle involves using one company's waste as a resource for another, benefiting both the environment and the economy. This partnership fosters local growth and supports the companies' CSR efforts and climate change mitigation strategies.

By exchanging materials, water, and energy, Kalundborg Symbiosis enhances resilience and economic benefits while reducing environmental impacts and costs. The goal is to continuously improve business practices, not just for mutual and environmental benefits.

While countries such as Denmark and the Netherlands lead the way with well-established frameworks and digital infrastructures supporting industrial symbiosis, other nations are still in the early phases of adopting these practices. This disparity highlights the need for tailored strategies and enhanced collaboration to ensure a more uniform progression towards sustainable and efficient resource management across the entire European Union.

Digital Industrial Symbiosis is largely driven by economic benefits achieved through mutually advantageous relations that lower costs, reduce risks, facilitate communication and ensure business sustainability. It is recognized as a catalyst for innovation. This approach offers benefits across economic, social, and environmental sustainability by leveraging technology to enhance the exchange of resources, information, and by-products between industries. It improves efficiency by enabling real-time data sharing and analysis, which helps identify potential synergies and optimize resource use. DIS facilitates faster and more accurate decision-making, reducing costs and minimizing waste. Additionally, digital platforms can broaden the network of participating organizations, increasing opportunities for collaboration and innovation. By integrating digital tools, Industrial Symbiosis can more effectively contribute to sustainability goals, reducing environmental impact and supporting the transition to a circular economy.

3. Research methodology

The study utilized secondary sources of information to conduct a comprehensive analysis of industrial symbiosis implementation across various European countries. In preparing this article, literature studies and reliable web pages about European Commission projects were used.

Through unstructured interviews with representatives of Chamber of Commerce and Industry Vratsa Sdruzhenie (Bulgaria); IURS - Institute for Sustainable Development of Settlements (Czech Republic), Confimi Industria Basilicata (Italy) it was possible to identify the barriers and challenges to IS development faced by different European countries. Interviews were conducted between December 2023 and June 2024.

Case studies of European countries and EU-funded projects were analyzed to understand the macro-level conditions fostering industrial symbiosis. Furthermore, statistical data from European databases were employed to assess the progress of industrial symbiosis initiatives across different countries.

Guided by the degree of innovation of European countries - on the basis of The European Innovation Scoreboard (EIS) report (European Innovation Scoreboard, 2024) - countries have been selected that represent varying degrees of innovation and, at the same time, implementation of the Digital Industrial Symbiosis.

The EIS provides a comparative assessment of the research and innovation performance of EU Member States and other European countries and distinguishes 4 groups of countries or regions: Innovation Leaders, Strong Innovators, Moderate Innovators, Emerging Innovators.

The following countries were selected for this review: Denmark and the Netherlands as Innovation Leaders; Austria and Norway (Strong Innovators); Greece, Czech Republic, and Italy (Moderate Innovators); Slovakia, Bulgaria and Poland as Emerging Innovators.

Using secondary sources, it was possible to summarize the current state of industrial symbiosis in these countries and to identify EU programs that support the introduction of DIS.

4. European landscape of Digital Industrial Symbiosis

The Industrial Symbiosis (IS) is one of the key tools identified by the European Commission to facilitate the progressive transition to a sustainable economic system based on a low carbon and resource-efficient economy. Such a concept in recent years has become a recognized approach for environmental improvements at the regional level.

The IS was incorporated into EU law in 2018, and Member States are now required to promote replicable practices. It is also a key component of the EU's Circular Economy Action Plan (CE Action Plan, 2020). Member States are invited to create the conditions for "facilitating Industrial Symbiosis by developing an industry-led reporting and certification system and enabling the implementation of industrial symbiosis".

This review examines the progress of various European countries in implementing industrial symbiosis as part of their circular economy strategies. Across Europe, countries exhibit different levels of advancement in adopting these practices, influenced by national policies, economic structures, and technological capabilities. This is even more evident when assessing the needs for DIS implementation. By comparing these efforts, we can identify best practices, highlight successful case studies, and understand the challenges faced in different contexts. This analysis aims to provide a comprehensive overview of the current landscape of Digital Industrial Symbiosis in Europe.

One of the European leaders in introducing the concept of Digital Industrial Symbiosis is Denmark; innovation index: 149.3 (European Innovation Scoreboard, 2024). With Kalundborg Symbiosis in Denmark being seen as the global pioneer project on industrial symbiosis, Denmark is working hard on bringing the IS also to smaller and more regional cooperation initiatives. Kalundborg is a collaboration between large to very large companies, showcasing how IS can be a competitive strategy, even after 50 years. However, extrapolating the learning to SME's and lesser developed regions of the country has been proven to be difficult.

In the Netherlands (innovation index: 138.3) (European Innovation Scoreboard, 2024), the local authorities are the primary body that is responsible for industrial symbiosis. There is a system for residents that allows recycling to happen more easily. However, businesses can use a helping hand with improving IS since it is less effort to dispose of waste materials rather than recycle them. There are subsidies available for SMEs relating to a circular economy but this is not enough. Several projects aim to equip the business community with knowledge related to Digital Industrial Symbiosis, but there are still more questions than answers on how to fully exploit the opportunities of DIS.

According to EIS Austria and Norway are "strong innovators", with the innovation indexes respectively 127.9 and 128.7 (European Innovation Scoreboard, 2024), what reflects their openness towards Industrial symbiosis.

The long-term goal of the Austrian government is to transform the Austrian economy and society into a comprehensive, sustainable circular economy by 2050. Financial support for circular economy projects and initiatives from public and private sources is therefore an important lever to accelerate the transformation. Under the EU's Recovery and Resilience Facility (RRF), Austria has applied for funding to support the following circular economy priorities for the period 2021-2026: waste prevention and resource conservation; collection quotas for plastic drinks packaging; and the construction and retrofitting of sorting facilities for plastic packaging (Austrian CE Strategy, 2024). To achieve this, close collaboration between industrial partners, also within the Digital Industrial Symbiosis framework, is essential.

In Norway, industrial symbiosis is vital for reaching the country's ambitious climate goals. To transition to a supportive regulatory environment for industrial symbiosis, Norway needs updated regulations, industry initiatives, and new guidelines for residuals and by-products. Nevertheless, SMEs are seen as crucial actors in this transition, given their role in the Norwegian economy and innovation ecosystem, but they are mostly followers in the development.

Italy (innovation index: 98,6) (European Innovation Scoreboard, 2024) has been recognized for its innovative approach to IS, particularly through regional and national initiatives that integrate IS principles into industrial processes and policies. Recently, diverse networks and platforms have been established: it's the case, for instance, of ENEA (2024), which aims to facilitate the exchange of information, resources, and technologies among businesses to foster IS. However, while there has been significant progress, increasing awareness and participation among small and medium-sized enterprises (SMEs) remains a challenge and the Government is studying how to adapt the regulatory frameworks to deliver a more comfortable environment.

Similarly, the Czech Republic (innovation index: 98,7 (European Innovation Scoreboard, 2024) has shown commitment to industrial symbiosis through initiatives such as its National Waste Management Plan and adherence to EU Circular Economy directives. These efforts aim to optimize resource utilization and minimize waste generation. Additionally, research and innovation funding have supported projects focused on developing technologies and strategies for industrial symbiosis. Industry associations and collaborative initiatives play an important role in promoting symbiotic relationships among businesses, sharing best practices, and advocating for supportive policies. Government support, including incentives and assistance programs, further encourages industries to adopt practices that promote sustainability. Education and awareness campaigns raise awareness about the benefits of industrial symbiosis, fostering a culture of resource efficiency and collaboration. Together, these efforts demonstrate the Czech Republic's commitment to advancing industrial symbiosis and contributing to a more sustainable economy.

Despite the fact that Greece is recognized as a “moderate innovator” – innovation index: 85,3 (European Innovation Scoreboard, 2024), Digital Industrial Symbiosis may be easily introduced in the region. IS in Greece is explicitly referenced within the (Action Plans…, 2018; NNRRP, 2021). Certain regions include support to IS investments as part of their Regional Operational Programmes, e.g., the regions of Attiki and Western Greece. Significant examples of successful IS in Greece include the Volos Business Park in Thessaly, where cement and concrete-producing industries reduce the industry’s water footprint, or in Dytiki Ellada, where feedstuff-producing industries use the fish farming packaging industry’s waste. Also, Greece participates in a digital solid waste reuse platform involving Albania, Bulgaria, Cyprus and

Greece. Serious challenges for the continuing growth of IS in Greece include human capital and finance.

Slovakia is a classic example of an emerging innovator. According to EIS its innovation index is 71,6 (European Innovation Scoreboard, 2024). The Slovak Environmental Strategy (SR Strategy…, 2019) prioritizes the transition to a circular economy. Industrial symbiosis is also gaining momentum, with initiatives led by the Institute for Circular Economy (INCIEN) and Circular Slovakia. Both platforms aim to connect the public and the private actors and foster collaboration among industries to optimize resource usage, minimize waste, and develop new, circular business models. However, despite its potential, a lack of awareness is still observed in companies and industrial actors. In addition, IS development is still hampered by environmental, economic, technical, regulatory, organizational, social, and cultural barriers. These findings indicate problematic issues of industrial symbiosis implementation in Slovak Republic and represent the gaps that need to be addressed. Therefore, Slovakia urgently needs new impetus to re-establish its competitiveness in the digital age. The digitization projects must be driven by clear objectives to stay globally competitive, resilient and environmentally sustainable and to become part of a powerful innovation ecosystem (EXPANDI, 2024).

In Bulgaria (innovation index: 50,6) (European Innovation Scoreboard, 2024), industrial symbiosis initiatives are gaining momentum, exemplifying the principles of a circular economy. One notable example is the partnership between the Devnya Cement Plant and the nearby Svilosa pulp and paper mill. In this collaboration, waste materials from the pulp production process are used as alternative fuels and raw materials for cement production. This not only reduces waste and emissions but also lowers symbiosis is known and applied mainly by large enterprises from the processing industry. Bulgarian's industrial symbiosis integration shows a diverse approach to sustainable industrial practices through national strategies, EU projects, and local initiatives. One notable example is the partnership production costs for both companies. Another example is the collaboration in the Plovdiv region, where agricultural waste from local farms is converted into biogas, which in turn powers industrial operations and generates organic fertilizers. These initiatives demonstrates how strategic redevelopment can promote urban and industrial symbiosis, sustainable land use, and business investment without financial incentives, highlighting the importance of integrating IS into Bulgarian's economic and environmental strategy. Despite these efforts, DIS awareness and knowledge in corporations remain difficult.

It should be noted, that despite being evaluated as an emerging innovator (innovation index: 72,5) two Polish regions: Małopolskie and Warsaw (capital region) are graded as the moderate innovators, with innovation index respectively: 87,0 and 103,2 (European Innovation Scoreboard, 2024).

In Poland, there is a growing awareness of the importance of IS for increasing the economy's efficiency and implementing more dynamic pro-environmental solutions. Still, for a large percentage of Polish enterprises, especially the smaller ones, waste management is associated only with complying with the legislative requirements regarding their treatment, transportation and recycling (Proszowska et al., 2024). There is not enough initiative regarding their utilization as a resource, as well as understanding of the benefits. The management of natural resources and industrial activities, waste generation and disposal, energy efficiency, demand on raw material for production are becoming urgent issues for our country. Individual good practices observed in Poland (e.g. green industrial parks) indicate a great potential for such solutions. At the same time, they show the need for organizational and financial support. Therefore, further research and projects developing industrial symbiosis are needed.

5. EU projects supporting the advancement of Digital Industrial Symbiosis

European Union programs, such as Horizon Europe or Erasmus Plus, actively support the implementation of industrial symbiosis principles. These initiatives provide substantial funding and resources to foster innovation, research, and collaboration among industries. By promoting eco-innovative practices and facilitating the sharing of resources, EU funding programs significantly contribute to the development of digital competencies and education in sustainable practices. Such programs foster a supportive environment for industrial symbiosis. In addition, these programs encourage partnerships between academia, industry, and policymakers, creating a conducive environment for developing and scaling industrial symbiosis projects. This support is crucial for advancing the circular economy and achieving the EU's sustainability goals.

5.1. Programs advancing Industrial Symbiosis

By strategically connecting companies from different industries, the Interreg Europe project BIS (BALTIC INDUSTRIAL SYMBIOSIS) promoted industrial symbiosis and helped boost eco-innovation. The project carried out nearly 40 business matchmaking events on local and transnational level. The events were ranging from one-to-one meetings between companies examining specific flow of resources (identified through the screening) to larger events considering broader fields of industrial symbioses. Transnational matchmaking granted regions with opportunities to identify companies from the neighboring countries that could help them to exploit the value of their resources more sustainably. Altogether more than 160 companies took part in the matchmaking events, some of them already signed agreements of collaboration. Besides, BIS succeeded not only in creating awareness of Industrial Symbiosis among a broad field of actors in the Baltic Sea region, but also in providing capacity building among supportive structures such as clusters and public authorities (BIS, 2019). Successful training programs were developed and implemented based on close cooperation with educational partners, and all training sessions were customized to each region (Screening Tool, 2021).

A survey conducted at regional level (2020-2021) as part of the project IN-SYMBIOSIS (Industrial Symbiosis efficiency for sustainable solutions in South Baltic area) showed a huge demand from industry to study and discuss scenarios of successful industrial symbiosis principles. During the process, it was found that in the field of industrial symbiosis there are no ready-made solutions, study visits are only isolated and rare, and there is a lack of sharing of experiences from good cases. There is a great need for partner-finding events, for training, for awareness-raising in this particular field of industrial symbiosis. Industries in the South Baltic region are able to switch to industrial symbiosis solutions more effectively, exchange good practices, find new business partners, increase skills, train staff, initiate new ideas for industrial symbiosis, if they are at least supported by regional experts in the field. Seed funding is needed to explore and structure the current state of knowledge in the field and to develop solutions to support cross-border cooperation in the exchange of experience and mutual cooperation in order to prepare a project concept to be used for the regular development of project proposals on the effectiveness of industrial symbiosis and the exchange of experience in the field (IN-SYMBIOSIS, 2024).

Through SYMBI project (Industrial SYMBIosis for Regional Sustainable Growth and a Resource Efficient Circular Economy) the Małopolskie Voivodeship has developed a methodology for collecting data on industrial symbiosis, the use of secondary raw materials and the circular economy at regional and national levels. In addition, a comparative analysis of public policies in the field of industrial symbiosis and CE for individual European Union (EU-28) countries was carried out, together with recommendations, e.g. on tax policy (abolishing VAT for products made from recycled materials, introducing tax breaks for companies applying industrial symbiosis). The added value of the project was to raise public awareness of the concept of industrial symbiosis and the circular economy and to promote public-private partnerships in pursuit of its implementation, as well as to encourage small and medium-sized enterprises to take advantage of synergies in the networking of separate economic sectors operating in this rapidly growing market (SYMBI, 2021).

Project RISERS (A Roadmap for Industrial Symbiosis Standardization for Efficient Resource Sharing) addresses developing a roadmap that defines areas, directions and proposes actions where standards are needed to advance industrial symbiosis with focus on priority resources and synergies demonstrating the highest symbiotic potential in Europe. Key activities of the RISERS project involve: identification of priority synergies between industries and sectors together with resources most relevant for industrial symbiosis, strengthening the links between R&I and standardization to valorize and integrate R&I results into IS standardization processes, cooperation with policy makers to develop policy frameworks in support of industrial symbiosis and engagement with standardization experts to develop a Standardization Roadmap for boosting IS impact complemented with guidelines for technical committees to address industrial symbiosis in standardization processes (RISERS, 2024). The project provides a consensus on the core elements of industrial symbiosis to enable its identification and on good practice approaches to implementation across Europe and beyond.

5.2. Focus on digitalization in EU programs

Many EU funding programs support the transition to a smarter, more digitalised Europe. Below are some examples of projects whose main objectives coincide with the implementation of the DIS.

The project TRUE (Transparency of Learning Outcomes through Blockchain Technology) focuses on the university's use of Blockchain technology demonstrating how different sectors (ICT, rectories, administration, students, etc.) can benefit from this technology. The innovative force of TRUE relies on its targeted approach of blockchain deployment for higher education purposes, resulting in the use of such technological infrastructure to secure the circulation of verified learning transcripts, diplomas and academic credits, thus enhancing transparency between HEIs, students and third parties (TRUE, 2020).

The REFRAME project (Circular Economy Strategy Framework for Sustainable SMEs) creates a CE Transition Framework specifically for small and medium businesses in construction, manufacturing and crafts industry, to help them become friendlier to the environment. It provides the EU construction & manufacturing SMEs and micro-enterprises' employees and future employees with practical knowledge on implementing CE transition in their business. A step-by-step framework for SMEs and micro-enterprises shows them how to scale up by understanding, utilising and investing in a Circular Economy, how to manage resources more efficiently and be friendlier to the environment (REFRAME, 2021).

The project European Digital Innovation Hub EXPANDI 4.0 (EXPANDI 4.0 - EDIH) is oriented towards the digitization of industry – SMEs with a particular focus on manufacturing. EXPANDI 4.0 shall support companies, regional and national institutions and policy makers - in finding the adequate technological solutions for implementation of Industry 4.0. Besides understanding the underlying technologies such as IoT, Big Data, AR/VR, AI, ML, sensor systems, robotics, additive manufacturing, predictive smart maintenance, etc., the outcomes of the project support companies to stay globally competitive, resilient and environmentally sustainable and to develop competitive manufacturing skills of digital age (EXPANDI, 2024).

5.3. Programs developing DIS competences

Implementing the principles of Digital Industrial Symbiosis requires education at various levels, with a particular focus on entrepreneurs and SME owners. This multifaceted approach ensures that the benefits of resource sharing and digital innovation are fully understood and effectively applied. By providing targeted training and resources, businesses can leverage the power of digital technologies to optimize waste reduction, increase resource efficiency and foster collaborative networks. This education should encompass practical skills, strategic thinking, and an awareness of the economic and environmental advantages, ultimately driving widespread adoption and success in sustainable practices across industries. The following are various EU projects that build the competencies needed to implement DIS.

The project TRANSITION (Foster Blockchain acquisition for entrepreneurs) aims to present the Blockchain technology to current and potential entrepreneurs and inspire them to adopt the technology in their business. Business hubs and incubators were also within the target group as they can further transfer the knowledge to their customers. The project‘s objective is to create and innovate teaching materials aimed at three crucial components of the entrepreneurial ecosystem: potential startup founders, entrepreneurial trainers/coaches working in business support organizations(accelerators, incubators, development agencies) and current entrepreneurs. These three categories need to be up to date with innovative technology trends and Blockchain is the tech revolution that most probably will change all the aspects of the business world forever (TRANSITION, 2019). Giving an integrated type of training to future entrepreneurs with general knowledge of the topic of Distributed Ledgers Technology along with entrepreneurial base competencies and the opportunities that this technology can open up for business making.

The I4U project (Industry 4.0 upskilling for SMEs) aims to develop a comprehensive set of educational programs and modules for digitalization of SMEs. The project will develop the concept for and implement 6 Upskilling Eco-systems which will bring together SMEs in labour intensive sectors with Vocational Education and Training (VET) Schools and High Education Institutions (HEIs) and other stakeholders involved in Digital transition/Industry 4.0 processes. The objective will be to build capacity on relevant digital competences and develop easy-to-access ICT training concepts by matching HEI/VET offers with SMEs upskilling needsTo support both collaboration within each Upskilling Eco-system and the access to training modules and knowledge about Industry 4.0, the project will develop the I4U Upskilling Eco-system Collaboration platform, which will enhance the cooperation between education and training, research, labour market, the public sector and the business sector to foster the adoption of common European digital competence frameworks (I4U, 2021).

5.4. Projects developing sustainable skills

Several Erasmus Plus projects support the development of digital capabilities and raising green awareness among scholars and students, based on the assumption that conscious students will soon enter adulthood, become entrepreneurs and employees who are informed about sustainable challenges and more open towards Digital Industrial Symbiosis networks.

The VR-WAMA project (Improve the Efficiency and the Attractiveness of Environmental Engineering and Waste Management Training with Game Based Virtual Reality) is a response to the continuing and urgent needs of the growing environmental engineering and waste management sectors to develop highly qualified VET students with great skills and competencies able to fulfil the sector needs for highly qualified and specialized professionals. Its objective is to enhance the students qualifications, expertise and skills and thus increase their employability and assist them to make a career in the environmental engineering industry, especially in the context of Industrial Symbiosis. (VR-WAMA, 2019)

The GoGreen project (Using Augmented Reality Technology and Simulation-Based Training to Foster Green Economy) supports the professional development of the private sector stakeholders and entrepreneurs and those willing to effectively support Green Economy through the development of a tailored green curriculum based on augmented reality technology, simulation training and an innovative Massive Open Online Course. The project aims at redefining disciplinary programs and educational methods through cooperation between the different institutions of education and providing theoretical-methodological schemes which are innovative and closer to the analyzed realities as well as virtuous models of action which will enhance environmental issues (GoGreen, 2022).

RAISE (Raising environmental knowledge & awareness through an innovative virtual environment) devised a 3D Virtual World Learning Environment which engages students/teachers, through transformative education to develop the knowledge, skills and attitudes to live more sustainably, change patterns of consumption and production, embrace healthier lifestyles and contribute – both individually and collectively – to the transformation of our societies and the promotion of Industrial Symbiosis. Through learning, students and learners of all ages can find solutions to challenges of today and the future. The 3D Virtual World Learning Environment". will engage students/teachers, through transformative education to develop the knowledge, skills and attitudes to live more sustainably, change patterns of consumption and production, embrace healthier lifestyles and contribute – both individually and collectively – to the transformation of our societies. Environmental education for sustainable futures could increasingly engage students in public life and participation, helping them to face socio-ecological crises caused by human activity (RAISE, 2022).

The project BESIDE (Blockchain use cases in digital finance) aims to present the Blockchain technology and how it can be beneficial to the financial providers (banks, insurance companies, etc.). In addition, the project aims to support the digital transformation of the vocational education and training sector by making the course and its resources for ongoing professional development, all the while adhering to the EU policies. The objectives and results of the BESIDE project align with the priorities of digital transformation and vocational education and training. The BESIDE project is designed to assist financial sector professionals in staying current with the latest developments and technologies in the industry, with a focus on the application of Blockchain technology in digital financial services, all in line with the objectives of the European digital policy (BESIDES, 2022).

Erasmus Plus project ETCASE (Education Towards Circular And Sustainable Economy) aims to drive this change from the grassroots level by educating the next generation. By raising awareness and inspiring young people about sustainability, the project lays the foundation for a society and economy that harmonize with nature. Using innovative teaching methods and hands-on activities, ETCASE demonstrates that sustainability is enjoyable and a collective responsibility. Today's students are viewed as tomorrow's changemakers. Through a collaborative international effort involving higher education institutions (HEIs) and NGOs, the project will implement innovative activities that include research, practical actions, and educational materials. The project's goal is to transform educational schemes by providing research-based guidelines, innovative instructional resources, and comprehensive teacher training to inspire and empower the next generation in circular economy practices (ETCASE, 2023).

The overall objective of the project REBUILT (ReEngineering BUsIness under cLimaTe crisis) is to develop and cultivate an effective innovation ecosystem of Higher Education Institutions, Business Communities and Research Institutions that contributes towards achieving an urgent environmental turning point. The specific objectives of the REBUILT project include: improvement of the match between curricula of Higher Education Institutes and human capital needs of businesses; development of future-oriented curriculum for Higher Education students and professionals; development of skills strategy and a low carbon transition action plan; raise awareness about environmental and climate-change challenges (REBUILT, 2024).

As the above overview shows, many projects funded by the European Commission directly or indirectly support the advancement of Digital Industrial Symbiosis. Many EU projects are dedicated to raising awareness about the circular economy and industrial symbiosis. These initiatives aim to develop competencies among young adults and entrepreneurs, which will ultimately facilitate the broader implementation of Digital Industrial Symbiosis across Europe. Through educational programs, workshops, and collaborative research, these projects strive to equip participants with the necessary skills and knowledge to integrate sustainable practices into their businesses and communities. By fostering a deeper understanding of the circular economy principles and the benefits of industrial symbiosis, these EU initiatives are laying the groundwork for a more sustainable and resource-efficient future, promoting innovation and cooperation among different sectors and stakeholders across the continent.

6. Conclusions

Industrial Symbiosis (IS) can contribute to achieving a win-win situation between industry and environment for local and regional circular economies. It can often create economic, environmental, and social benefits, which assists in promoting local and regional sustainable development through the collaboration and the synergistic possibilities offered by geographic proximity. However, both creation and operation of IS remain complex and dynamic processes, which requires continuous improvement.

The circular economy aims to eliminate waste through innovative business models and cooperation among industries, supported by digital platforms and regulatory frameworks. Therefore DIS may play a vital role in this system, but practical implementation faces numerous barriers. Continued research and strategic initiatives are essential to overcome these challenges and realize the full potential of a circular economy.

A review of the situation in various EU countries has been conducted to highlight the diversity in the field of industrial symbiosis across Europe. This examination reveals notable differences in how countries adopt and implement industrial symbiosis practices, with some nations displaying advanced and well-established systems, while others are still in the developmental stages. By illustrating these disparities, the review offers a comprehensive insight into the current state of industrial symbiosis in Europe, underscoring the need for customized strategies and collaborative efforts to enhance the adoption of sustainable practices across the region.

While Nordic countries have been pioneers in adopting national strategies and regional initiatives to promote IS, many other countries with less developed industrial sectors or those facing economic challenges didn’t not prioritize it or allocated public investments in industries that offer quick returns on investment over those requiring long-term strategy and collaboration. Industrial Symbiosis is a relatively new challenge, not clearly integrated into the regional development strategies or into academic curriculum and training courses: this means that symbiotic mechanisms are unlikely to be initiated from the bottom without the push and support of both public funding and expert players who can act as promoters and coordinators of such a complex process (Akyazi et al., 2023).

The European Commission actively supports the implementation of industrial symbiosis through Horizon Europe or Interreg programs, providing funding and resources to foster innovation, research, and collaboration among industries. These initiatives promote eco-innovative practices and facilitate resource sharing, contributing to the development of digital competencies and sustainable education. Projects like BIS, IN-SYMBIOSIS, SYMBI, and RISERS have demonstrated the benefits of industrial symbiosis, such as reducing carbon emissions, preserving critical resources, and ensuring business sustainability, while also highlighting the need for continued partner-finding events, training, and awareness-raising activities. With regard to the advancement of DIS, projects like TRUE or REFRAME illustrate the EU's commitment to enhancing digital capabilities and fostering a circular economy. These initiatives demonstrate the EU's holistic approach to integrating digital and sustainable practices.

Furthermore, Erasmus Plus projects emphasize developing digital and green skills among students, entrepreneurs, and professionals. These projects aim to cultivate a new generation of informed individuals capable of driving sustainable change and implementing industrial symbiosis principles.

Overall, EU-funded projects significantly contribute to advancing Digital Industrial Symbiosis by promoting education, innovation, and collaboration. By equipping participants with the necessary skills and knowledge, these initiatives are laying the groundwork for a more sustainable and resource-efficient future, fostering cooperation among various sectors and stakeholders across Europe. This general review may serve as a basis for exploring possible opportunities for international cooperation in the development of Digital Industrial Symbiosis platforms and for defining research guidelines in this area in the context of promoting the circular economy.

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CHALLENGES AND OPPORTUNITIES OF ERP AND SCADA SYSTEMS IN ESG REPORTING

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Purpose: The purpose of this paper is to analyse the challenges and opportunities associated with the application and integration of IT systems, particularly Enterprise Resource Planning (ERP) and Supervisory Control and Data Acquisition (SCADA), in the collection, processing and reporting of ESG data.
Design/methodology/approach: The study is based on a mixed method approach that combines a review of the literature with quantitative and qualitative analyses, based on pilot data collected among small and medium-sized enterprises (SMEs) in Poland.
Findings: The research showed that the integration of ERP and SCADA software can significantly increase the efficiency of monitoring and reporting ESG indicators by automating processes and improving data quality and consistency. The main challenges include high implementation costs, data fragmentation, compatibility limitations, and lack of uniform standards.
Research limitations/implications: The data from the pilot study are focused on SMEs in Poland, which limits the generalisability of the results.
Practical implications: Integration of ERP and SCADA systems improves data management processes, including data for ESG reporting, reducing reporting costs, and ensuring compliance with the CSRD and ESRS standards. Research indicates that key actions for small and medium enterprises (SMEs) and software vendors include the development of competencies for the automation of ESG reporting and the more efficient implementation of sustainable business practices.
Social implications: Improving ESG reporting promotes greater transparency and accountability, which can influence public trust and support for sustainable practices. The study highlights the potential social benefits of implementing robust ESG systems, such as reduced environmental impact and improved corporate responsibility.
Originality/value: The article fills a research gap by analysing the applicability of ERP and SCADA systems in ESG reporting in the context of CSRD requirements in SMEs in Poland. It provides relevant lessons for policy makers, business leaders, and technology providers, highlighting the potential of IT systems integration in automating processes, improving data quality, and supporting sustainability in line with ESG regulations.
Keywords: ERP, SCADA, ESG Reporting, CSRD, Sustainability.
Category of the paper: Research paper.

1. Introduction

In the face of increasing sustainability and social responsibility requirements, small and medium enterprises (SMEs) face the need to adapt their management processes to new regulations. The Corporate Sustainability Reporting Directive (CSRD) (Directive (EU) 2022/2464), introduced by the European Union, is a key element of these changes. Although its requirements are not mandatory for SMEs, social and economic pressures increasingly require companies to disclose detailed environmental, social, and corporate governance (ESG) information (Ozkan et al., 2023; Kuzior et al., 2024). The main objective of the CSRD is to increase the transparency and quality of reporting of sustainability-related activities, which necessitates the use of advanced systems to collect, process, and report data. Adapting to these requirements is particularly challenging for SMEs, which often face technological, financial, and organisational constraints. Traditional data collection methods, such as manually collecting and entering data and information into spreadsheets, are characterised by poor quality of the resulting outputs, frequent errors, and delays, making it significantly more difficult to meet regulatory requirements (KPMG, 2024). In this context, integrated IT systems (Dudek and Kulej-Dudek, 2024) supporting management, e.g., ERP (Enterprise Resource Planning) (Ruivo et al., 2012) and SCADA (Supervisory Control and Data Acquisition) systems, which enable automation of processes, improvement of data quality (Borda et al., 2024), and monitoring of ESG indicators, can play an important role. The integration of these systems with modern technologies, such as artificial intelligence (AI) and the Internet of Things (IoT) (Huang et al., 2024; Boye et al., 2023), creates new opportunities for ESG data acquisition and management, allowing for efficient data acquisition, analysis, and reporting. The implementation of modern solutions for ESG data acquisition and reporting in an enterprise is associated with a number of challenges, such as high implementation costs, lack of appropriate technological competence, and compatibility issues with existing systems (Tutak, Brodny, 2024). Therefore, it is worth considering integrating already functioning solutions and extending them with new, dedicated functionalities. The use of integrated IT technologies has significant potential to meet the requirements of the CSRD, improve the quality of ESG data, and support the implementation of sustainability strategies (Székely et al., 2017).

In this context, advanced technological systems such as enterprise resource planning (ERP) and supervisory control and data acquisition (SCADA) are becoming crucial (Martins, Belfo, 2023). These systems offer the ability to automate and streamline the processes of collecting and reporting data that can be used directly or indirectly for ESG reporting. This approach increases the accuracy and quality of the reporting, making it more compliant with the European Sustainability Reporting Standards (ESRS). Despite their potential, the implementation and integration of these technologies, especially in small and medium enterprises (SMEs), presents numerous challenges, such as high implementation costs, limited technical resources, and organisational barriers. In Poland, the verification of ESG reports will be carried out by auditors (Act of 6 December 2024), making this process an important element in the professionalisation of sustainability reporting. At the same time, it forces companies to raise their reporting standards. To meet increasing regulatory requirements, organisations should invest in improving the quality of ESG data (Biju et al., 2023). One solution is the use and integration of management support systems (e.g., ERP, SCADA) and training of teams responsible for reporting (Hossain, 2023).

CSRD requires that ESG reports be independently verified by auditors or other accredited bodies. Their main tasks are to assess the compliance of the report with the ESRS, to ensure the consistency and completeness of the data in the context of the sustainability objectives, and to identify and report noncompliance and ESG risks. The audit verification of ESG reports plays a key role in ensuring their credibility and compliance with regulations, including the European Sustainability Reporting Standards (ESRS) and the requirements of the CSRD. The purpose of the audit is to confirm the reliability, completeness, and accuracy of ESG disclosures, which promotes transparency and builds stakeholder confidence. The scope of the audit covers three key areas: environmental indicators (e.g., CO2 emissions, waste management) (Afshan et al., 2024; Lin et al., 2025), social aspects (e.g., diversity policy, employee rights) and corporate governance (e.g., internal control systems, anticorruption). Verification is based on international standards, such as, e.g. GRI, SASB and ESRS, and auditors apply procedures analogous to those used in the audit of financial reports, including, inter alia, compliance testing and risk analyses. Auditing for ESGESG by auditors is not only a regulatory requirement but also a tool to support responsible management and sustainability of organisations.

Individual ERP software modules (https://www.comarch.pl/erp/esg/), once indicators have been standardised and appropriate reporting algorithms have been created based on the right selection of attributes and entities, can play a key role in the ESG reporting process and in meeting the requirements of the CSRD. Dedicated software / modules can provide tools to manage data and processes in different areas of the organisation. The financial module in conjunction with the production module will enable the consolidation of ESG data, such as CO_2 emissions or RES production (Dao, 2022; Gu et al., 2023), with financial performance, supporting the production of reports compliant with ESRS. The HR module (Martins, Belfo, 2023) will monitor diversity policies and respect employee rights, providing social data. The production module will track energy and resource consumption, waste management, and optimise processes for sustainability. The supply chain management module (SCM) will support the monitoring of sustainable supplier practices and the management of the carbon footprint of logistics (Lin, Li, 2024). The sales and marketing and CRM modules will allow reporting of corporate social responsibility (CSR) activities and analysis of the environmental impact of products. The Analysis and Reporting (BI) module will provide advanced analytical tools such as forecasting and analysis of key ESG indicators. In addition, the compliance and document management modules will support the control of compliance with ESRS regulations and the automation of ESG reporting workflows. The integration of a project management module will allow the monitoring of ESG initiatives such as emission reductions or infrastructure upgrades (Osnes et al., 2018). SCADA system modules (Sbjörnsson et al., 2024; Molinari et al., 2023) would play a key role in the ESG reporting process and in meeting the requirements of the CSRD. The monitoring and visualisation module would enable visualisation of environmental data, such as CO_2 emissions, and real-time monitoring of ESG indicators. The control module would support remote management of processes and automation of operations to minimise environmental impact. A data archiving module would store historical data that could be used for ESG analyses and ESRS-compliant audits (Ab Aziz et al., 2023). An alerts and notifications module would generate alerts when emission or resource consumption standards are exceeded, allowing rapid intervention. The reporting module would automate the creation of ESG reports, visualise the results, and support their compliance with the ESRS. The integration module with external systems would allow data exchange with ERP and IoT, enabling the consolidation of ESG information. The analytics and optimisation module would identify trends in resource consumption and support process optimisation to achieve sustainability goals. The user management module would provide access control to ESG data and its security. The communication and protocols module would enable the transfer of ESG data between devices and the central database, ensuring transmission reliability. The maintenance management module would support the planning of technical activities and equipment upgrades, which would contribute to reducing resource consumption. A cyber security module would protect ESG data from unauthorised access, ensuring its integrity and confidentiality. A mobile access module would allow operators to remotely monitor and manage ESG reporting. The integration of ERP and SCADA systems will enable companies to meet CSRD requirements and improve the quality of ESG reporting. ERP modules support the management of data and processes in different areas of the organisation, while SCADA modules provide data monitoring and analysis for ESG reporting in real time (Szmechta et al., 2013). The collaboration of these systems allows for operational optimisation, reduced reporting costs, and effective implementation of sustainability goals. The integration of ERP and SCADA systems enables comprehensive business management, combining operational and business data to optimise processes and meet requirements, e.g., in ESG reporting (Barakat et al., 2024; Dao, 2022). ERP systems play a key role in consolidating operational and financial data, enabling their effective management and analysis. SCADA systems, on the other hand, support real-time data monitoring, which is particularly important in the context of dynamic indicators such as CO_2 emissions or natural resource consumption. The integration of these systems allows the automation of ESG reporting processes and the improvement of data quality, which is essential to meet the stringent requirements of the European Sustainability Reporting Standards (ESRS).

One of the main challenges for small and medium companies (SMEs) is the quality of ESG data (Kotsantonis et al., 2019), its often poor quality resulting from the use of manual methods to collect information, such as spreadsheets. This results in errors, delays, and inconsistencies, making it difficult to comply with CSRD requirements. ERP and SCADA systems offer the potential to address these issues through automation and data standardisation. Nevertheless, their implementation in the SME sector faces technological and organisational barriers such as high implementation costs, lack of technical competence, and system compatibility issues.

The literature (Dudek, Kulej-Dudek, 2024) also highlights the importance of modern technologies such as AI (Artificial Intelligence) and IoT (Internet of Things), Big Data, Blockchain (Baker, 2023; Kuzior et al., 2023), which, when combined with ERP and SCADA systems, enable advanced ESG data analysis and trend forecasting. These technologies support real-time monitoring of ESG indicators and integration of data from different sources, which is key to creating comprehensive and reliable reports.

Another aspect discussed in the literature (Huang et al., 2024) is the role of ESG auditing, which is an important element in the professionalisation of sustainability reporting. The verification of ESG reports by auditors requires high data quality and compliance with international standards. Such an audit covers key areas, including environmental, social, and corporate governance indicators, which increases transparency and stakeholder confidence. The low level of implementation of ERP and SCADA systems in SMEs in Poland indicates an urgent need for investment in technology and the development of competencies related to their implementation. It is particularly important to provide financial support, such as grants or investment allowances, which can help overcome cost barriers. Furthermore, the development of technology awareness and training for management and staff is key to maximising the full potential of these solutions. ERP and SCADA systems, supported by modern technology, are an essential tool to improve ESG reporting (Martins, Belfo, 2023). Their integration enables the automation of processes, improvement of data quality, and compliance with the requirements of the CSRD, while contributing to the achievement of sustainability goals. However, the introduction of these systems in SMEs requires overcoming numerous technological and organisational barriers, which represents a challenge but also an opportunity to develop innovative business practices.

2. Materials and Methods

The research carried out to assess perceptions of the role of data acquisition and to identify challenges and opportunities associated with the implementation of ERP and SCADA systems in the reporting of ESGs was based on a mixed methods approach, combining qualitative and quantitative research techniques. The main objective of the study was to analyse the potential for the use of management support systems in small and medium enterprises (SMEs) in Poland in the context of ESG reporting. The potential of these technologies to ensure compliance with the requirements of the CSRD and the possibility of using existing data sources to improve the quality and consistency of the data necessary for reliable reporting was also considered.

The utilitarian objective of the study was to fill the research gap by analysing employee and management attitudes towards the use of ERP and SCADA systems in ESG reporting processes and to develop recommendations for companies and software developers. Specifically, the study focused on assessing how these technologies can support the overcoming of current challenges such as low data quality for ESG reporting, high implementation costs of ESG specialist software, lack of technological competence or system integration issues. Furthermore, the potential of using existing technology solutions to automate and standardise ESG reporting processes and their role in promoting sustainable business practices in the SME sector was analysed. The results of the study provide valuable insights into the practical applications of ERP and SCADA systems and their potential integration with modern technologies, such as artificial intelligence (AI) and the Internet of Things (IoT), to effectively manage ESG data and adapt to increasing regulatory requirements.

The qualitative research included a review of the academic literature related to ESG reporting and the use of ERP and SCADA systems to identify key challenges and opportunities that arise from the implementation of these technologies. It analysed how the use of these systems can support data integration, data quality improvement, and compliance with ESG regulations such as the CSRD and ESRS standards. This approach provided a deeper understanding of the role of these technologies in sustainability reporting processes.

The quantitative part of the study consisted of a survey aimed at small and medium enterprises (SMEs). A structured questionnaire was used to collect demographic data and analyse the opinions of the respondents. The survey covered key issues such as the level of technology adoption, barriers to implementation, and the perceived benefits of using existing IT solutions for ESG reporting.

The pilot research sample comprised 41 SMEs from various sectors of the economy, focussing mainly on the southern Poland region, where manufacturing and trading companies stood out in particular. The survey was primarily aimed at those responsible for sustainability issues in the companies surveyed. The analysis shows that these were mainly managers and executives, providing insight into organisational perspectives on ESG compliance and readiness for the integration of technologies to support sustainability reporting. The results allowed for an assessment of the extent to which ERP and SCADA systems can be used in data capture and reporting and the identification of barriers.

Demographic analyses took into account variables such as gender, age, education, and professional roles of participants to understand their impact on readiness to implement ESG and perceptions of the role of modern technologies or readiness to adopt them. The level of integration of ERP and SCADA systems and their functionalities to support ESG reporting were assessed. Barriers such as high costs and competence gaps were also identified. The scope of the study was geographically limited to Poland and the analyses were mainly based on pilot data. However, it provided valuable information on the adoption of ERP and SCADA systems in ESG reporting. Future studies can cover a wider sample and allow cross-country comparisons to generalise the results. The methodological approach adopted provided a holistic view of how advanced technology systems can support ESG data management, regulatory compliance, and sustainable business practices.

For most of the closed questions, the responses were rated on a scale of 1-5, where 1 meant total disagreement and 5 meant full agreement with the statement. A Likert scale was used to score the survey to assess perceptions and the impact and potential role of ERP and SCADA technology on the effectiveness of ESG processes.

This study provides an opportunity to analyse the challenges and opportunities for the use of ERP and SCADA systems in ESG reporting in small and medium enterprises (SMEs), the issues are divided into four key areas: assessment of data quality and efficiency of data acquisition processes, use of tools and implementation of ESG support systems, technologies and their integration in ESG reporting, and barriers and challenges. This division allows for a comprehensive discussion of the topic, starting with an analysis of the current situation in terms of data quality and tools used, through the identification of the most promising ESG support technologies and opportunities for their integration, to a discussion of the barriers and challenges faced by companies. Research was carried out to better understand perceptions of the role of data acquisition in ESG reporting and to assess the potential of ERP and SCADA systems to overcome the difficulties of acquiring reliable and high-quality data. They also allowed an analysis of the potential for effective use of these data in reporting. Challenges associated with the implementation of ERP and SCADA systems in SMEs to increase compliance with ESG regulations were also identified. The purpose of the survey was to identify which data acquisition and management support systems, according to the respondents, hold the most promise for ESG reporting processes. It also explored whether these technologies have the potential to improve ESG reporting and increase compliance with regulations such as the CSRD. A key element was to assess the quality of the data and the efficiency of the data capture processes in the context of the challenges and opportunities associated with the use of ERP and SCADA systems. The analysis considered both the difficulties and opportunities for the development of IT systems in data acquisition processes and their application in reporting. The study identified the extent to which and how these systems can support the acquisition of data necessary for reliable reporting in line with the requirements of the CSRD and address technical and organisational barriers. On this basis, a detailed assessment of the quality of the data and the efficiency of the data capture processes was carried out.

3. Results and Discussion

Analysis of the demographics of survey respondents on the challenges and opportunities of using ERP and SCADA systems for ESG reporting provides important information on their diversity in terms of gender, age, education, type of business, and location of company headquarters. The results make it possible to identify the professional groups and industries most involved in the implementation of IT systems to support ESG reporting.

In terms of gender, the proportion of men (51.22%) and women (48.78%) is almost equal, indicating widespread interest in implementing ERP and SCADA systems among both men and women. This suggests that ESG reporting using advanced technology tools is considered an important topic regardless of the gender of users.

The largest group of respondents were those 45 to 54 years of age (51.22%), followed by those 35 to 44 years of age (29.27%), indicating the dominance of experienced professionals and managers playing a key role in the ERP and SCADA implementation processes. Younger individuals, under the age of 25, accounted for only 2.44% of respondents, which may reflect fewer years of experience in this area. In addition, as many as 90.24% of respondents had a university degree (Master's, Bachelor's or Engineering) and only 9.76% had a high school education, suggesting that the implementation and use of ERP and SCADA systems in ESG reporting requires advanced knowledge and skills, more often found among those with higher education.

The largest number of respondents came from manufacturing (31.71%) and trading companies (29.27%), while service companies accounted for 21.95%. Other categories, such as educational, scientific, or trade/service companies, accounted for 4.88%. The dominance of manufacturing and trading companies may be due to their greater need to collect and analyse process and logistics data, making SCADA and ERP systems crucial for ESG reporting.

A significant proportion of the respondents were decision makers, including senior management (22.00%) and middle management (19.51%). The business owners accounted for 12.20% and the administrative staff 17.07%. This structure indicates the proportion of people who influence the implementation of technology and ESG strategies in organisations. In terms of location, companies from southern Poland dominated, with the majority coming from the Silesian Voivodeship, reflecting the concentration of industry in this region. Demographic analysis indicates that the implementation of ERP and SCADA systems in ESG reporting is most advanced in manufacturing and trading companies.

ERP and SCADA technologies show significant potential in improving the efficiency of reporting processes through automation, error reduction, and increased data quality. A key aspect of the research was to assess the feasibility of using them to meet the requirements of the CSRD and to analyse the challenges and opportunities associated with implementing these systems in ESG reporting. The results indicate the significant benefits that can be derived from the use of these technologies, both in terms of improving data quality and operational efficiency. The research carried out has provided a better understanding of the role of data acquisition in ESG reporting and the potential of ERP and SCADA systems to overcome the difficulties associated with acquiring reliable and high-quality data, as well as its effective use in reporting. The quality of the data and the efficiency of the data capture processes were evaluated, identifying the support opportunities that these systems offer in the context of CSRD-compliant reporting. The perceptions of companies of the data used in ESG reporting indicate serious problems in this area. As many as 43.90% of companies rate their existing data as low or very low quality, which is a significant barrier to meeting regulatory requirements such as the CSRD. The largest number of companies (26.83%) indicated difficulties in using the data they already have, and 17.07% of respondents believe they do not have reliable data for ESG purposes. Only 2.44% of the respondents believe they have very high-quality data. In this context, ERP and SCADA systems, through their ability to automate processes and better structure data, can significantly improve data quality. In addition, by cross-correlating existing data, these systems can generate new information and, with a slight extension of the databases with additional attributes, enable synergies to be achieved when analysing and inferring based on new entities. This approach can significantly increase the accuracy and efficiency of ESG reporting. The implementation of these technologies helps overcome the difficulties of obtaining high-quality data, eliminating qualitative and quantitative errors resulting from manual input of information, while ensuring greater consistency and reliability.

An evaluation of the effectiveness of ESG data collection tools shows that 53.66% of companies rate their tools as neutral, suggesting that there are no clear benefits or problems associated with their use. On the contrary, 26.83% of respondents from the companies surveyed rate these tools as ineffective or very ineffective, indicating an urgent need to upgrade them. Only 12.20% of companies rate their tools as effective or very effective, suggesting that the companies surveyed lack integrated and automated solutions to support ESG reporting. ERP and SCADA systems can be key tools in this area, as they enable the automation of data collection processes and the integration of data from different sources using relational databases, providing the opportunity for effective data collection and reporting including ESG data.

Aligning companies' data capture processes with ESRS requirements remains a significant challenge. Only 2.44% of companies rate their processes as fully compliant with ESRS requirements, while 39.02% indicate a low degree of alignment and 14.64% consider their processes noncompliant with the regulations. ERP and SCADA systems can significantly support companies in complying with regulatory requirements by enabling the integration of the data they have from different sources, automating the analysis and acquisition of data, and transforming it into information useful for reporting on specific indicators. The proper integration of these systems allows companies to comply with ESG standards faster, cheaper and with less effort, consequently increasing compliance with the requirements of the CSRD.

With the ability to automate processes and make efficient use of data, ERP and SCADA contribute to eliminating technical barriers and streamlined reporting processes.

The analysis of the responses regarding the potential of already existing and applied tools used or possible to be used in the ESG reporting process showed that the respondents assessed the ERP and SCADA systems as tools with significant potential in the effective collection and processing of data, as well as being important to ensure regulatory compliance.

The study also identified opportunities for further expansion and integration of these systems, which could improve the consistency and accuracy of the information captured. An important element of the analyses was an assessment of the ability to use and implement IT systems already present in companies or easily implemented to support ESG reporting. Respondents highlighted the key role of ERP and SCADA systems as tools to increase data collection efficiency, including sustainability. An important aspect of the survey was an analysis of the tools currently used in SMEs to collect and analyse data that can be used for reporting on ESG. It was shown that in many cases traditional approaches such as manual data entry in spreadsheets and reports dominate (58.54%). These approaches are associated with risks of errors, delays, higher costs, and more work.

An important element of the research conducted was to analyse the potential of different types of software for information processing, indicator analysis, and the preparation of ESG reports. The aim was to identify the potentially most effective tools to support these processes, taking into account their ability to integrate data and comply with regulations such as the CSRD. The study identified opportunities for the use of advanced technologies to improve the quality and effectiveness of ESG reporting. Analysis of the survey results shows that ERP systems were considered by 39.02% of respondents the most promising tool to support the ESG reporting process. Their popularity is due to their ability to integrate operational and financial data, making them an important element in the effective management and analysis of ESG information. SCADA systems, identified by 17.07% of respondents, stand out for their ability to monitor data in real time, which is particularly important for dynamic indicators such as energy consumption, raw materials, or emissions.

Artificial intelligence (AI) technologies alone were rated useful by 12.20% of the respondents, highlighting their role in advanced analysis and forecasting of complex ESG data. The Internet of Things (IoT), although identified by only 4.88% of respondents, offers potential for real-time data collection, but its importance in ESG reporting appears to be less recognised among SMEs. The survey also identified perceptions of the applicability of integrated technology solutions. The results show that 9.76% of the respondents see the potential of integrating ERP systems with SCADA or ERP with AI, indicating a growing awareness of the benefits of technology synergies. On the contrary, 4.88% of the respondents indicated the combination of IoT and AI, suggesting that the full integration of modern technologies is not yet widely prioritised among SMEs. At the same time, 2.44% of the respondents were unable to identify the appropriate tools, which may indicate a low level of awareness of available IT solutions to support ESG reporting.

The findings indicate that, in the minds of decision makers, ERP systems will play a key role in ESG reporting, particularly in terms of data integration and analysis, making them an essential tool for companies seeking regulatory compliance. The low awareness of the ability to fully integrate technologies such as ERP, SCADA, AI and IoT highlights the need for education and awareness among businesses. Although SCADA and AI technologies are less popular, their potential in optimising ESG processes, especially in monitoring indicators in real time, is significant. The results of the survey also highlight the need for training and awareness of modern technologies. A gradual and functionality-aware implementation of integrated IT systems, starting with ERP, can help companies minimise costs and risks, while increasing efficiency and compliance of ESG reporting with regulations such as the CSRD. The survey results indicate that ERP systems are seen as the most promising tool to support ESG reporting, due to their ability to integrate operational and financial data. At the same time, SCADA and AI technologies have gained recognition as key elements supporting real-time monitoring of ESG indicators and data analysis. However, the integration of modern technologies such as IoT and AI remains a challenge due to limited awareness of their capabilities among SMEs.

A significant problem identified in the research is the failure to fully exploit the potential for synergies between different IT systems. Only 9.76% of the respondents indicated that they combined ERP with SCADA or AI and 4.88% incorporated IoT and AI. This demonstrates the need to educate businesses on the benefits of advanced integration of ESG-supporting technologies.

In summary, the results of the study highlight the importance of automation, integration, and the development of analytical tools in the ESG reporting process. The implementation of advanced IT systems, such as ERP and SCADA, can significantly improve data collection and analysis processes, improving consistency and regulatory compliance. However, fully exploiting the potential of technology requires both investment in IT infrastructure and competence development among staff, which is a significant challenge for the SME sector.

An analysis of the responses on the potential of current tools and technologies in the ESG reporting process (Table 1) indicates that the ERP and SCADA systems are rated by the respondents as tools with significant potential in the effective collection and processing of data and key to ensuring regulatory compliance. The survey also revealed opportunities for further expansion and integration of these systems, which can improve the consistency and precision of the information captured. An important element of the analyses was an assessment of the ability to use and implement IT systems that are already present in companies or can be easily implemented to support ESG reporting. The respondents highlighted the key role of ERP and SCADA systems as tools to increase the efficiency of data collection, including sustainability data.

Table 1.
Results of responses to the question: Which software / IT tools should potentially be used in the ESG reporting process in your company?

Software/IT tools	
ERP (Enterprise Resource Planning)	39.02%
SCADA (Supervisory Control and Data Acquisition)	17.07%
AI (Artificial Intelligence)	12.20%
IoT (Internet of Things)	4.88%
ERP and SCADA	9.76%
ERP and AI	9.76%
IoT and AI	4.88%
None of the above/I don't know	2.44%

The survey analysed the tools currently used by SMEs to collect and analyse ESG-related data. It showed that in many cases traditional approaches, such as manual data entry in spreadsheets and reports, are dominant (58.54%). However, these approaches are fraught with the risk of errors, delays, higher costs, and more work. Therefore, the implementation of advanced technologies, such as ERP and SCADA systems, can significantly improve the quality and efficiency of ESG reporting.

Analysis of the survey results shows that 39.02% of the respondents considered ERP systems to be the most promising tool to support the ESG reporting process. Their popularity is due to their ability to integrate operational and financial data, making them an important element in the management and analysis of ESG information. In contrast, SCADA systems, identified by 17.07% of respondents, stand out for their ability to monitor data in real time, which is particularly relevant for dynamic indicators such as energy consumption or emissions. Artificial intelligence (AI) technologies were rated as useful by 12.20% of the respondents, highlighting their role in advanced analysis and forecasting of complex ESG data. The Internet of Things (IoT), identified by 4.88% of the respondents, offers potential in real-time data collection, but its importance in reporting on ESG appears to be less recognised among SMEs.

The survey also identified perceptions of the potential for integrated technology solutions. The results show that 9.76% of the respondents see the potential to integrate ERP with SCADA or ERP with AI, indicating a growing awareness of the benefits of technology synergies. In contrast, 4.88% of the respondents indicated the combination of IoT and AI, suggesting that the full integration of modern technologies is still not widely perceived as a priority among SMEs. At the same time, 2.44% of the respondents were unable to identify relevant tools, which may indicate a low level of awareness of available IT solutions to support ESG. ERP systems are seen to play a key role in ESG reporting, especially in terms of data integration and analysis. The low awareness of the potential for full integration of technologies such as ERP, SCADA, AI, and IoT highlights the need for education and increased awareness among businesses. Although SCADA and AI technologies are less popular than ERP, their potential in optimising ESG processes, especially monitoring indicators in real time, is significant.

The survey results also highlight the need for training and technological competence to support the implementation of integrated IT systems.

The surveys identified technologies that can support ESG reporting and identified key areas for optimisation in data acquisition and processing. The results of the survey indicate that the greatest potential in ESG reporting is attributed to ERP and SCADA systems, which are rated as key tools for automation, data integration, and improving data quality and regulatory compliance.

In order to identify the key technical areas that require optimisation in ESG reporting, an analysis was carried out that included data processing automation, integration of different systems, analytical and visualisation tools, real-time data collection and data structuring and standardisation. The most important area for optimisation, identified by 26.83% of the respondents, is data processing automation. Traditional data entry methods, such as manually filling in spreadsheets, have a high risk of errors and delays, which significantly reduces the quality of the report data. Automation not only enables the elimination of errors but also speeds up the analysis process, which is crucial in a dynamically changing environment. Integration of data from different systems, indicated by 19.51% of the respondents, is another technological challenge that needs to be addressed. Many SMEs use dispersed data sources, making it difficult to collate data consistently. ERP and SCADA systems, with their ability to consolidate data, can significantly improve the quality of ESG reports by integrating operational and financial information.

The development of analytical and visualisation tools, also indicated by 19.51% of the respondents, plays an important role in improving the quality of ESG reporting. Advanced analytical tools support the identification of trends and enable a clearer presentation of the data, which increases its usability for both internal and external stakeholders.

Real-time data collection, highlighted by 17.07% of respondents, is particularly important in sectors where key ESG indicators, such as emissions or energy consumption, change rapidly. In these applications, SCADA systems, supported by IoT technologies, enable real-time monitoring of indicators, which is essential to make fast and accurate operational decisions. The final area for improvement is the structuring and standardisation of the data for the ESG indicators, also identified by 17.07% of the respondents. The introduction of uniform data standards, in line with ESG regulations such as the CSRD, would facilitate their analysis and the automation of reporting processes (Table 2).

Table 2.
Survey results for the question: Which technical areas require the most optimisation to improve ESG reporting?

Which technical areas require the most optimisation to improve ESG reporting?	
Data Processing Automation	26.83%
Integration of data from various systems	19.51%
Analytical and Visualisation Tools	19.51%
Real-time data collection	17,07%
Data Structure and Standardisation	17.07%

The survey identified key barriers and challenges to the integration of ERP and SCADA systems in ESG reporting processes. Analysis of the survey results indicates significant technological and organisational difficulties. Among the technological barriers, the high costs of implementing new IT systems and solutions, problems with compatibility of systems from different manufacturers or generations, and the lack of qualified human resources were singled out. At the same time, organisational challenges, such as lack of knowledge and competence of staff and resistance to change, significantly hinder the effective implementation of technologies to support ESG reporting.

The research identified key barriers to the implementation and integration of ERP and SCADA systems in ESG reporting, considering both technological and organisational challenges. The main technological constraints include high implementation costs (17.07%), lack of staff competence (14.64%), and system compatibility issues (12.20%), which hinder the effective collection, processing, and analysis of ESG data. These limitations significantly reduce the ability of companies to meet regulatory requirements.

In the organisational area, lack of knowledge and competence (43.90%) and unclear regulatory requirements (34.15%) were found to be the biggest obstacles. Reluctance to change, indicated by 34.15% of the respondents, and insufficient management support (14.64%) further complicate the implementation of new technologies. Deficiencies in training and experience, highlighted by 26.83% of respondents, highlight the urgent need to develop ESG competencies and technologies to support the process. Despite these challenges, ERP and SCADA systems were evaluated as tools with great potential in ESG reporting, especially in terms of automation, data integration, and data quality improvement. The survey also highlighted the potential for further integration of these systems, which could significantly improve the consistency and accuracy of information. The use of existing IT systems that can be adapted to meet ESG requirements was identified as a key element in minimising costs and increasing reporting efficiency.

Research points to the need for investment in IT infrastructure, development of technological competence, and ESG education. Removal of organisational and technological barriers, as well as increasing awareness of the benefits of integrating ERP and SCADA systems, can significantly improve reporting processes. Despite the initial costs, implementing these technologies is a necessary step towards sustainable and effective ESG reporting that complies with current regulations.

4. Conclusions and Recommendations

The research and analysis carried out indicated the significant potential of ERP and SCADA systems in ESG reporting, especially in terms of improving data quality, process automation, and compliance with regulatory requirements. The main technological barriers are high implementation costs, lack of staff competence, and system compatibility issues, which limit the ability of companies to effectively collect, process, and analyse ESG data. Organisational difficulties, such as lack of knowledge and competence and reluctance to change, further hinder technology implementation, pointing to the need for management education and support.

However, respondents recognise the potential of integrating ERP and SCADA with AI and IoT technologies to enable end-to-end ESG data management, real-time monitoring of indicators, and automation of reporting processes. ERP systems integrate operational and financial data throughout the supply chain, while SCADA provides real-time monitoring of manufacturing processes to support environmental management and CSRD compliance. The integration of these systems improves data consistency, quality, and efficiency, while reducing the risk of errors.

The results of the research indicate an urgent need to modernise ESG reporting tools, especially in the SME sector, where manual data collection methods dominate, generating errors and delays. Improving reporting quality requires the implementation of integrated IT systems that allow data structuring and analysis in accordance with ESRS standards. The gradual implementation of ERP and SCADA technologies, supported by financial support and the development of technological competencies, can help companies overcome implementation barriers and raise awareness of their benefits.

Integrated ERP and SCADA solutions, when expanded with new functionalities, have the potential to become key tools in ESG reporting, supporting the optimisation of operational processes, reduction of reporting costs, and implementation of sustainability strategies. Their integration with AI and IoT technologies will allow for a more complete use of data, resulting in better environmental management and regulatory compliance. The implementation of these systems, although it requires investment, is a key step toward effective and efficient ESG reporting.

Based on the research and analysis carried out, key recommendations were made on the use of ERP and SCADA systems in reporting for sustainability and sustainability purposes.

Automating data collection and processing processes using ERP and SCADA systems reduces errors resulting from manual data entry and improves analysis. Integration of SCADA systems with ERP enables real-time monitoring of indicators, which significantly improves the efficiency of reporting processes.

The development of technologies integrating ERP, SCADA, AI, and IoT supports the comprehensive management of ESG data, improving its quality, consistency, and compliance with the requirements of the CSRD and ESRS standards. The implementation of dedicated modules for structuring and standardising ESG data and reporting tools that enable the automatic generation of reports and streamline audit processes is crucial.

Companies must develop advanced analytical and visualisation tools to monitor key ESG indicators and respond to environmental exceedances in real time. Optimising processes for monitoring resource consumption and emissions through SCADA integration with ERP can contribute to reducing the carbon footprint and increasing operational efficiency.

It is important to implement ESRS-compliant IT systems and to provide training to employees in the use of ERP, SCADA systems and knowledge of ESG-related regulations. Raising organisational competence and awareness is key to the successful implementation of ESG-supportive technologies.

The SME sector should gradually introduce ERP and SCADA systems, focussing on key business areas, but should integrate solutions to support ESG reporting from the outset.

Financial support in the form of grants or concessions can help overcome economic barriers to the implementation of IT solutions also for ESG reporting. Problems with system compatibility and resistance to change can be mitigated by promoting innovative solutions and highlighting the benefits of implementing new technologies.

Digitisation of supply chain processes, including automation of data collection and integration of IT systems, allows effective monitoring and reporting of ESG data.

Summary

ERP and SCADA systems, supported by modern technologies such as AI and IoT, offer significant potential in automating ESG reporting processes, improving data quality, and ensuring compliance with CSRD requirements. The implementation of these systems eliminates manual data entry errors, integrates information from different sources, and monitors ESG indicators in real time. Such solutions contribute to the optimisation of operational processes and the implementation of sustainability strategies.

Despite the numerous benefits, the implementation of ERP and SCADA systems, especially in small and medium enterprises (SMEs), faces significant challenges, such as high implementation costs, problems of compatibility of systems with current software, and lack of technological competence. At the organisational level, key barriers include resistance to change and low awareness of the synergies of technology integration for ESG reporting.

However, these difficulties also represent an opportunity for development. The gradual deployment of integrated systems, financial support for SMEs, and the development of technological competencies among employees and managers are key to realising the full potential of these technologies. The integration of ERP and SCADA with AI and IoT is not only an opportunity to help meet ESG regulatory requirements, but also increases the operational efficiency and competitiveness of companies in the market.

To overcome technological and organisational barriers, actions such as collaboration with technology providers, ESG education, and management commitment to integrate technology with sustainability goals are required. The identified lessons point to the need for increased investment in advanced systems and alignment of business processes with new requirements, allowing companies to effectively manage ESG reporting and meet long-term sustainability goals.

The research conducted highlights the need for further analysis of the feasibility of implementing modern systems to support ESG management and reporting. Particular attention should be paid to identifying implementation barriers, assessing the effectiveness of existing solutions, and developing recommendations for integrating ERP, SCADA systems in terms of new functionalities related to data analysis for ESG needs. Such an approach supported by modern technologies such as AI and IoT will allow to streamlining reporting processes in line with the requirements of the CSRD Directive and the ESRS standards.

This paper discusses the challenges and opportunities associated with the implementation and development of ERP (Enterprise Resource Planning) and SCADA (Supervisory Control and Data Acquisition) IT systems in the collection and processing of ESG data. The study indicates how these systems can support the acquisition of reliable data necessary for reliable reporting and eliminate technological and organisational barriers. The integration of ERP and SCADA systems improves data quality by automating processes, enables real-time management of dynamic ESG indicators (e.g., emissions, resource consumption) and ensures compliance with regulations such as the CSRD and ESRS standards.

Through better data and process management, strategic sustainability goals can be achieved and reporting costs reduced. Investment in ERP and SCADA systems, the development of analytical tools, and the employment of ESG experts are key to increasing competitiveness and regulatory compliance. Integrating these technologies supports companies in effectively managing ESG reporting, meeting regulatory requirements, and long-term sustainability goals.

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SUPPORT SYSTEM FOR START-UPS IN POLAND – SELECTED ASPECTS OF THE HEALTH CARE SECTOR

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Purpose: The purpose of this paper is to analyse the role of innovation and business ecosystems in supporting start-ups, particularly in the healthcare sector. The study focuses on the stages of start-up development - innovation, business model creation, market testing, investor acquisition and product marketisation - and identifies forms of support at these stages. The topic of the article was taken up because of the growing pressure for efficient and affordable healthcare delivery. The growing contribution of start-ups to this challenge is noted, but research in this area is lacking.
Design/methodology/approach: The study uses literature review methodology combined with exploratory secondary data analysis. Key sources include academic publications, industry reports and case studies, looking at innovation ecosystems, business ecosystems and the medtech start-up environment in Poland. The analysis was designed to highlight the interconnectedness between ecosystem actors and the specific needs of start-ups at different stages of their development.
Findings: The study identifies key gaps in the flow of information in the area of healthcare innovation, especially in the relationship between start-ups and investors, customers and other participants in the ecosystem. It highlights the importance of structured support mechanisms, such as mentoring, funding or market access, to overcome barriers at different stages of start-up development. The results also point to the need for synergies and sustainable collaboration to increase the effectiveness of innovation ecosystems.
Originality/value: The paper contributes to the understanding of how innovation and business ecosystems can support the development of start-ups, particularly in the health sector. It provides a structured approach to analysing the needs of start-ups and the types of support needed for their success. The findings are valuable for policymakers, investors and ecosystem stakeholders seeking to strengthen the medtech sector and support innovation in healthcare.
Keywords: start-up ecosystems, innovation ecosystems, healthcare innovation, medtech start-ups, start-up support, business model development, venture capital.
Category of the paper: General review.

1. Introduction

Start-ups, as dynamic and innovative business entities, play a key role in shaping the modern economy by bringing disruptive technological and social solutions to the market (Audretsch et al., 2020). Their development, while full of potential, comes with numerous challenges that often require support in various areas. When considering start-ups, we need to take into account the broader context in which they operate, not only locally but also globally (Mátyás et al., 2019). The challenges currently posed by start-ups are closely linked to a dynamically changing world (Kowalewski, 2020). There is a faster transfer of knowledge, skills, technology or capital between markets (Kusio et al., 2023). The covid-19 pandemic has had a large impact on the growth and acceleration of technological and working model change, with significant changes in thinking about the supply chain or challenges in the health tech sector (Katić, 2020). Demographic and social changes cannot go unnoticed. Changing consumer expectations, especially among new, younger generations (Łukasiński, Nigbor-Drożdż, 2022) and the need to adapt to an ageing population. The global healthcare sector is currently undergoing an unprecedented transformation (Morande, 2020), driven by technological advances, demographic changes and evolving patient needs (Deloitte, 2024). This has given rise to an attempt to review the support system for start-ups in this rapidly changing sector. Effective and affordable health care delivery for all is the prerogative of national governments. Such delivery is quite challenging and there are significant gaps. As a result, startups are trying to feed the market with innovative solutions and reach an underserved market. The phenomenon is noticeable nevertheless lacks confirmation in research (Chakraborty, 2021). The research gap in this area in Poland is even larger which became the reason for taking up the topic of the article. The purpose of the article is to analyze the conditions of the start-up health care sector in the current innovation and business ecosystems supporting start-ups. The intermediate goal is to assess the effectiveness of the support received. The premise of the article was to determine the market and management activities undertaken by start-ups of the health care sector which gives an idea of their condition.

2. The start-up ecosystem

In order for a start-up to develop properly, a properly functioning system is needed to support its development (Grycuk, 2019). Many factors influence the proper development of a start-up, these include: legal regulations, economic regulations, institutional regulations, human capital, social capital and the institutional environment. These factors play a key role at the different stages of start-up development viz: the seed stage in which an idea is conceived and turns into real action, the growth stage in which the project begins to develop and take on its final version and the final stage or stabilisation and expansion in which the product/service begins to scale. All these stages need to be supported by supporting activities so that innovation development does not stagnate or get lost (Blank, Dorf, 2013). With the growing needs of start-ups, the ecosystem surrounding them is also developing. Therefore, the paper attempts to analyse the start-up ecosystem in Poland to see its current state. Most start-ups die at the initial stage of operation, i.e. the seeding stage. A common problem that prevents them from moving on to the next stage is the lack of financial support, which makes it impossible for the start-up to successfully start growing (Cegielska, Zawadzka, 2017). As research in Poland shows, start-ups are predominantly funded from their own resources, but recently this trend has slowly started to change and more and more money from a private investor is entering the market. The start-up ecosystem, which consists of institutions such as business incubators, accelerators, technology parks, local and governmental activities, university activities and the European Union, is developing quite rapidly in Poland, but it is not as mature as in Western countries (Kuźmińska-Haberla, Bobowski, Michalczyk, 2020). Each enterprise, in order to develop effectively, must function in a favourable environment. The development of an enterprise is influenced by various factors, both intra-organisational and external. The higher the level of risk posed by an enterprise's activities, the more difficult it is to maintain on the market. An important role in its mitigation is played by the ecosystem in which it is located (Dziewit, 2021). A business ecosystem, which fosters cooperation between companies, investors, universities and R&D institutions, creates an environment that enables start-ups to grow effectively. The concept of a business ecosystem was pioneered by J.F. Moore, who argued that, companies are not just members of a specific sector in which they operate, but form a system that interacts with each other (Moore, 1993). Such a system is driven not only by competition but also by co-evolution. The interaction of companies with each other promotes their faster growth. J.F Moore's theory is a kind of extension of the theory on value chain networks. These factors are important for the development of a business and they determine the speed at which a business can grow. In this context, businesses are moving away from focusing solely on competing with other organisations in order to increase their competitiveness in the market. They are setting the customer as their main focus and it is for them that they want to increase the attractiveness of their offering. The consumer becomes the main driving force through which the business ecosystem can develop more rapidly (Wiechoczek, 2020). A well-functioning business ecosystem fosters the development of innovative solutions. Through mutual cooperation, companies can exchange resources, which increases the chances of success. The above considerations indicate the typical characteristics that define a business ecosystem. They include: a large number of organisations operating in a given ecosystem, the existence of interconnections and interdependencies between organisations, and dynamic co-evolution. The traditional approach, where the structure is based on a hierarchy and centred around a single business entity, is now being abandoned. Collaboration between entities is a fundamental element of any larger organisation. The business ecosystem is a complex system of mutual, value-creating inter-organisational interactions.

According to R. Adner, a business ecosystem is an opportunity to produce value that a company would never be able to produce if it were not for mutual cooperation with other actors (Adner, 2006). A business ecosystem can be likened to an innovation ecosystem. An innovation ecosystem is a dynamically evolving community of organisations and individuals that compete and collaborate, formed for a specific purpose. There are complex interactions between actors, and the basis for their functioning is trust, and the creation of shared value using available technology and knowledge (Autio, Thomas, 2014).

Within the innovation ecosystem, start-ups have access to resources, knowledge and networks that allow them to take their ideas and bring them to market (Knop, 2018). This linking of start-up support to the wider ecosystem fosters the dynamic development of new technologies and business models that change the face of the economy. To achieve the desired success, it is necessary to provide the right conditions for the development of the innovation ecosystem, including start-ups, which play a key role in this process. Creating an enabling environment requires support from various institutions and market participants (Janiszewski, Szmal, 2018). It is important that all elements of the ecosystem, including start-ups, work together in an effective and integrated manner. The development of the innovation ecosystem also depends on creating space for experimentation and risk-taking, especially in the context of young companies (Brzóska, Szmal, 2020). The right conditions will allow for dynamic growth and the realisation of innovative goals in which start-ups can play a key role. For this to occur, they need:

- Central nodes (Central node) This is a kind of base on which cooperation between actors is possible (Bae, Chang, 2012). Examples include:
  - IT platform.
  - Tool.
  - Innovative technology.
  - Configuration of social factors or economic conditions.
- Large number of actors involved in the ecosystem. Each of the actors in the ecosystem brings specific value and mutual cooperation brings success closer. It is characteristic of the innovation ecosystem and the business ecosystem that no single actor acting separately would achieve similar success. Each actor in the innovation ecosystem structure can play one of three roles (Isckia, Lescop, 2009):
  - Keystone - Is responsible for the functioning of the ecosystem by creating the focal nodes. He or she is also responsible for distributing the benefits among the actors co-creating the ecosystem, there is a (win-win) principle here.
  - Physical dominator - Usually a large organisation characterised by the fact that it imposes a development strategy on the entire ecosystem. It benefits from the focal nodes and niches of the ecosystem. An organisation operating in this way often

works against the ecosystem. Often, dominant actors become value controllers (value dominator) or become hub landlords.

- Niche actors - these are small entities or even individuals who provide key value to the development of the ecosystem by gaining access to a central hub. They are responsible for the development of a service or product, thus becoming a key link in the functioning of the innovation ecosystem.

Given the diversity that can exist in an innovation ecosystem, it is important to carefully select stakeholders (Szmal, 2021) to ensure synergistic development, including start-ups, which play a key role in the process. It is also essential to properly regulate collaboration and maintain a balance, which promotes dynamic development. The absence of a key player, responsible for maintaining this balance, can lead to a situation where one of the participants, including start-ups, is less effective in influencing the development of the ecosystem. It is important that each party participating in the ecosystem, including young companies, benefits, thus ensuring a "win-win" situation and enabling start-ups to fully exploit their innovation potential.

3. Start-up entity

In order to better analyse the conditions in which start-ups operate, it is worth looking at the attributes of a start-up. The term start-up in everyday language is currently heavily abused and sometimes extremely different from the definitions quoted in the literature.

The term Start-up was first used in Forbes biweekly in 1976. Nevertheless, one of the most popular definitions is that of S. Blank. He developed a modern management method which is known as Lean start-up (Tomaszewski, 2018), he stated that start-ups can be defined by: purpose, functions and financial structure (Blank, 2013). Purpose is understood to mean that the company has far-reaching plans to become a large enterprise that will influence or create new markets through its operations. Function, understood as continuous change in the business model. The search for the optimum solution to answer the questions raised earlier. Financial structure - characterised by the fact that the company raises external capital, which is needed for the development of innovative solutions, while reducing the share capital of the people who founded the start-up. From the above definition, it can be concluded that the most important characteristics of a start-up are the constant search for the ideal business model and the pursuit of business scalability (Montani, Gervasio, Pulcini, 2020). This definition is often complemented by operating under extreme uncertainty (Ries, 2011). This emphasises how vulnerable the start-up's business is to the uncertainty associated with the changes it wants to make.

Start-ups grow rapidly and focus on identifying and developing the ideal product or service. They stand out for their high growth potential (Kowal, Szmal, 2022), especially in the future, and often operate in areas of the technology industry where innovation plays a key role. Their mission is to bring innovative solutions to existing markets or to create entirely new markets. Start-ups tend to be companies with a short history, operating for no more than five years, and are characterised by a high degree of uncertainty related to the implementation of the intended changes. In addition, the lack of an established market position makes start-ups particularly vulnerable to risk, but at the same time they can be a catalyst for disruptive innovation.

Start-ups are characterised by a high level of uncertainty, which is due to the various factors affecting the launch of a product (Jonek-Kowalska, Wolniak, 2021). During the innovation process, it is difficult to predict how long it will take to match the product to market expectations and needs. This is due to the testing phase that every product/service has to go through in order to finally get the product to the customer (Lara et al., 2011). On the one hand, a lot of time is needed to successfully match an innovative product to customer needs while, on the other hand, the market requires entrepreneurs to act quickly. In order to reconcile these two aspects, entrepreneurs often seek external funding (Szmal, 2017), which will help them accelerate the testing process and, moreover, allow them to further refine their product. The entire operation stage of a start-up company can be depicted in the diagram below.

Figure 1. Stages of a start-up.

Source: Own work based on: Adamczyk, Bill, Bohatkiewicz, p. 6.

4. Research model

A literature review on start-up support was conducted using the desk research method. The bibliography includes 40 items, mainly from 1993-2024, including academic papers, books, monograph chapters, industry reports and electronic sources. The following databases were used to collect scientific literature: Google Scholar, ResearchGate, ScienceDirect, EBSCO. The literature search in the above databases used the following combination of words using logical operators (AND, OR): ('start-up support' OR start-up support in Poland) AND (resources OR 'activities'). Searches in the above databases complemented the literature collected for the following keywords: Start-up ecosystems, innovation ecosystems, start-up support, business model innovation, venture capital, product-market fit, entrepreneurial support.

This paper uses a report created by the Polish Federation of Hospitals and the Young Medical Managers team 'Top Disruptors in Healthcare 2021'. The report is based on an identified list of 380 Polish entities that operate in the healthcare sector. 115 start-ups participated in the 2021 edition. Data collection was carried out through online surveys made available to interested start-ups. The paper also drew on the Deloitte report, 2024 Global Health Care Sector Outlook - Navigating transformation, which provided a rationale for discussing the challenges facing health care. The overview of the challenges enriched the description of the conditions for start-ups and thus the required forms of support.

5. Support for start-ups at different stages of development

Start-ups need the right support at different stages of their business to successfully move through the stages of business model innovation, market testing, finding investors and the final product. In the right ecosystem, start-ups can benefit from the resources, knowledge and contacts that enable them to achieve market success (Scale, 2017). Each stage of a start-up's development is associated with different challenges and needs, which can be met by appropriate support. In particular, start-ups need support in the form of resources, knowledge and contacts to move through each stage in an effective and sustainable manner. In the innovation stage, start-ups often struggle to develop a new idea or technology that will stand out in the market. Consequently, support at this stage focuses on access to research, technology and experts to help validate the idea and assess its market potential (Jajuga, 2020). This support can come from universities, R&D institutions, accelerators and incubators that offer start-ups access to technology resources, laboratories and R&D teams. Additionally, participating in mentoring from experienced entrepreneurs and industry professionals allows for early identification of problems and opportunities in product development, which significantly increases the chance of success (Sanchez-Burks et al., 2017). The next key stage is the development of a business model, which defines how revenue will be generated, the cost structure and how customers will be reached. At this stage, start-ups need support to analyse the market, identify customer segments, and build a marketing and sales strategy. Support can take the form of advice from business experts who help to clarify the business model, build strategy and define the growth path. Incubation and acceleration programmes also offer workshops, training and access to networks, which allows for networking with other companies or institutions that can support the development of the business model. At this stage, start-ups also gain knowledge of legal and regulatory aspects, which allows them to build a solid foundation for future operations. When the product is ready to be tested in the market, start-ups face the challenge of verifying their idea in real market conditions. At this stage, support is crucial, as start-ups need tools to conduct trials, collect user feedback and test the product under real market conditions. Incubators and accelerators often offer start-ups access to focus groups, testing platforms, and analytical tools to collect data on consumer behaviour and reactions to the product. Marketing and promotional support is also important so that market tests can reach a wide range of potential users and start-ups can get valuable feedback. At the fundraising stage, start-ups often need support in the form of capital and strategic advice. Investors such as business angels, venture capital funds or innovation funds play a key role in this process. In addition to funding, investors also offer start-ups advice on growth strategies, entering new markets, as well as operational and organisational issues. In addition, investors help build networks that can prove invaluable in the further development of the company, enabling collaboration with business partners, customers and other companies in the innovation ecosystem. At the product finalisation stage, support focuses on commercialising the product and bringing it to market. Start-ups need help with sales strategy, marketing and building a distribution network. This support ranges from advice on marketing strategy to access to sales platforms to reach a wide audience. At the same time, start-ups need to focus on further refining the product and adapting it to changing market needs. Incubators and accelerators, as well as business partners, offer support in terms of production, logistics and sales, allowing the finished product to be brought to market faster and scaled up successively.

Each of these stages is crucial to the development of a start-up, and the right support at each stage can significantly increase the chances of success. Understanding these stages and the forms of support at each stage allows for better alignment of start-up development support activities in the context of the overall innovation ecosystem.

6. Findings and discussion

There are factors forcing change in the health care field (Deloitte, 2024) and a significant information deficit a significant information deficit in the healthcare sector, which makes it extremely difficult and time-consuming to get answers to questions about new and interesting solutions, their sophistication and maturity, as well as their needs, challenges, potential users and positioning against competitors. The analysis of the 'Top Disruptors in Healthcare 2021' report points to the need to develop an innovation ecosystem in healthcare, which not only fosters innovation in the economy, but also raises awareness among patients and enables collaboration between start-ups and others. A critical analysis of the 'Top Disruptors in Healthcare 2021' report, which contains a description of 115 Polish healthcare start-ups, allows us to see many interesting facts and relationships.

Seventy-four start-ups participated in the 2020 edition, 44 of which reappeared in the 2021 edition. The remaining 30 start-ups, despite attempts to make contact, did not participate in the next edition. This situation may suggest that some of them have gone out of business, which is due to the fact that start-ups operating in the medical industry rarely achieve market success. More than half of the start-ups surveyed, as many as 55%, indicate telemedicine as their main area of activity. According to the predictions of the Polish Agency for Enterprise Development, the global telemedicine market is expected to grow at a rate of nearly 20% per year for the next five years, reaching a value of USD 175 billion (Mańkowska, 2022). In contrast, 45% of respondents report that their business is focused on solutions related to artificial intelligence and machine learning. A quarter of the start-ups surveyed (25%) fund their activities from their own resources. At the expansion stage, this percentage rises to 37%. This may suggest that start-ups at this stage of development are sufficiently advanced to do without external funding, or that Poland lacks adequate sources of financial support. At the MVP stage, some start-ups have raised funding in excess of PLN 10 million, which shows that ambitious medical projects are able to attract investors, even if the company does not yet have its first paying customers. On the other hand, start-ups at the Proof of Concept stage receive the lowest funding, which indicates the reluctance of medical investors to commit capital to projects without a prototype, although there are exceptions. Financing with own funds shows, on the one hand, the founders' strong belief in their venture and, on the other hand, can mean difficulties in raising external capital. Grants are another important source of funding, used by 34% of start-ups (EU grants) and 31% (national grants). Incubation programmes support 13% of start-ups and acceleration programmes support 9%. This is significant support, especially given the high costs and barriers to entry in the medical sector. Despite this, only 9% of start-ups have received funding from foreign investors, showing little international interest in this market. Funds from private investors, so-called business angels, support 21% of start-ups, while 23% use VC funds. This is a relatively high percentage, indicating the willingness of private investors to take risks in the area of medical start-ups, which may be due to their high social utility. In contrast, crowdfunding was not used by any of the respondents, which may indicate its low popularity in this industry in Poland. Most of the start-ups included in the Report operate in the form of a limited liability company, which is the most preferred solution. On the other hand, other legal forms, such as general or limited partnership, which are commonly used in Poland due to tax advantages, are not very applicable in the start-up environment. As many as 90% of the start-ups surveyed have a product with a market value of at least Minimum Viable Product (MVP), i.e. a version of the product with enough features to meet the needs of initial customers and get the feedback needed for further development. More than half (53%) are already offering their products commercially, gaining their first paying customers. Around 30% of the start-ups surveyed are at the Growth stage, focusing on acquiring new customers and developing their products, while only 10% are at the Proof of Concept stage, where the product demonstrates its feasibility but does not yet meet key user requirements. The vast majority of the start-ups surveyed already have a business model in place and only 8% (9 start-ups) indicate a lack in this area. The survey shows that 44% of the start-ups surveyed (50 entities) indicate that CE certification is not required for their products. At the same time, 30% (34 start-ups) already have this certificate and 27% (31 start-ups) are only planning to obtain it. At the Proof of Concept stage, no start-up has a CE certificate, while 29% of start-ups at the MVP stage, 38% at the commercialisation stage and 46% at the expansion stage have this certificate. These figures indicate that almost half of medical start-ups need CE certification to successfully scale their business and succeed in the market. The research shows that 56% of start-ups are not yet active in foreign markets, although the majority have plans to internationalise. The largest number of start-ups that intend to expand internationally are currently at the Minimum Value Product stage, which applies to 28 entities.

The above findings are a good basis for assessing the effectiveness of support arising from the start-up ecosystem and for formulating recommendations on the expected forms of support necessary to scale business, including internationally.

Although health technology startups are increasingly filling gaps in affordability, accessibility and quality of health care through innovative solutions, only a few are sustaining and successful. Knowledge of the critical success factors is limited and should be helpful to stakeholders of health technology startups. A similar conclusion is also found in other studies (Chakraborty, 2023b). The research suggests that the classic startup architecture consisting of value proposition, co-creation, transfer and capture is not fully practiced in the Polish market. Exploration of this thread is in the research plans of the study's author.

The surveyed players are focusing their activity on telemedicine and artificial intelligence. This finding confirms that they fit into major global trends but unnoticed trends such as Wearables and health monitoring devices, fintech in health care or biotechnology and personalized medicine.

Another group of findings relates to the sources and structure of start-up financing. Developing a start-up in the healthcare sector can require significant investment in research, development, product testing and meeting regulatory requirements. Start-ups often have to raise capital from venture capital funds, with the risk of losing control of the company and requirements for a quick return on investment. Insufficient funding can lead to difficulties in maintaining liquidity and delays in growth. The findings point to the inadequacies of the innovation ecosystem in providing adequate venture funding.

The results of the survey also confirmed that start-ups have defined MVPs and business models, indicating the right level of support in this area.

A disturbing finding is that most start-ups do not operate in foreign markets. This is a significant problem. While many startups in Poland are off to a great start, they often face difficulties in scaling their business, especially in international markets. There is a lack of experience in managing rapid growth, entering new markets and building sustainable business models on a large scale. The weakness of the innovation ecosystem in this regard is evident here.

A valuable direction for further research seems to be to consider the determinants of the healthcare sector. These can certainly include: clinical risk, efficiency of medical procedures, regulatory aspects, social and ethical responsibility, cooperation with corporate partners and healthcare providers.

7. Conclusions

Undoubtedly, the start-up support system in Poland has been undergoing a significant change in recent years. More and more institutions operating in the start-up environment are being established. Currently, innovative enterprises can take advantage of a wide range of business incubators, technology parks, accelerators and university-related institutions. This is related to the growth of foreign capital in Poland, but also to the increased interference of government and EU institutions in innovation activities. The development of innovation is noticeable, but there are many elements that require significant changes to improve the functioning of the system. One of the main elements that should be improved is the availability of adequate sources of financing for development. The situation in this area is quite complex. Most start-ups, especially at the beginning, rely on their own funds. This makes it very difficult to enter the market with an innovative product or service. This can be seen in the Start-up Poland and Deloitte reports, which show the actual scale of the problem. On the other hand, there is an upward trend showing that start-ups in Poland are increasingly financed by Venture Capital funds. Nevertheless, the results of the research show that money to finance innovative projects is waiting for start-ups, but there are not enough interesting ideas that they are willing to invest in. This shows that another important element in increasing the effectiveness of the start-up ecosystem is to increase support for the invention stage, i.e. the creation of innovative ideas. The supply of resources for the development of innovation is significant and there is often a lack of projects and teams that offer the expected market appeal. Therefore, it is important to support the ecosystem in involving more people in the creation and implementation of innovative ideas. In Poland, there is a big problem with the financing of innovative companies by banking institutions. There is no specific bank that provides larger loans for future revenues. Compared to Western countries, there is much room for improvement in this area. An equally important challenge facing innovative companies is the ability to successfully raise both public and private funds. This ability is critical to the process of scaling the business.

Human capital was identified as the main factor responsible for the success of a start-up by the institutions and start-ups surveyed. Startups, especially in the healthcare industry, need experts who understand both technology and regulation in the medical sector. The combination of technical knowledge with market experience, contacts with other companies, sales skills and knowledge of social behaviour is key to the start-up's ultimate success. The support of the ecosystem in this respect is improving, but still needs perfection. Promotional and networking activities are also needed as many professionals are not very keen to get involved in the start-up development process

According to the start-ups, the ecosystem in Poland is not yet mature enough. This assessment is influenced by the fact that there are still too few tools on the market in Poland that would help start-ups to develop properly. The more mature it is, the more likely it is that a start-up will be able to achieve success. The maturity of the ecosystem can be indicated by the level of support from which innovative enterprises benefit. In Western countries, where the ecosystem is mature, the number of start-ups benefiting from VC funds, business angel support, technology parks or accelerators is much higher. Moreover, a mature ecosystem is characterised by the fact that it not only supports the activities of existing start-ups, but also drives entrepreneurs to take the initiative by giving them tools to support the invention and testing stage from the beginning. It should also be noted that the ecosystem of support for Healthcare start-ups in Poland takes into account to a modest extent the specific requirements of this process resulting from the marketisation of medical technologies or biomaterials. However, little has been published on their role in the evolving digital healthcare ecosystem. (Chakraborty, 2023a). This aspect also requires the attention of the players in the start-up support ecosystem.

The issue of the support system for start-ups in the health sector is an important gap. It is evident in both European and Polish dimensions. Despite the potential for feasibility, research on health technology startups for the provision of healthcare services is emerging, but only just beginning (Chakraborty, 2021). The review indicates that research on startups is insufficient, especially with regard to entrepreneurship, business frameworks and regulations. The research deficit in this area in Poland is even greater. The article's findings only show the main problems and future research should examine these issues in depth. Despite the limitations of the results, they provide clear confirmation of the need for exploration of the topic and can serve as a source of recommendations. The result can be used by startup developers, regional and national authorities creating support policies and other stakeholders in the innovation ecosystem. The condition of the startup support ecosystem and the forms of support needed are particularly relevant in view of the new challenge. In the spring of 2024, the European Parliament and the Council reached political agreement on the Commission's EHDS proposal. The European Health Data Space (EHDS) will be a key pillar of a strong European Health Union and is the first common EU data space in a specific area to emerge from a European data strategy. This regulation is a challenge but also a huge opportunity for innovative start-ups delivering value to increase health care accessibility. Research results can support this European competition.

In conclusion, Poland has great potential for startup development, but this requires further work to remove barriers related to funding, regulation, access to talent, and building the right structures to support innovation. Collaboration between the public, private and academic sectors is crucial to create a more favorable ecosystem for startups, especially in such a challenging sector as health.

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HOW EMISSIONS AT SOURCE AFFECT ENVIRONMENTAL AND ECONOMIC EFFICIENCY OF ELECTRIC BUSES? A COMPARATIVE CASE ANALYSIS

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Purpose: The purpose of the research is to compare the impact of inclusion emissions at source on environmental and economic performance of replacement of combustion engine powertrain with the electric or hybrid one, given the transport work on a selected public transport line on urban areas. It provides the gross emissions of pollutants and greenhouse gases related to total transport work executed on given bus line.
Design/methodology/approach: Primary data was collected from one of the public transport operators running its business in Upper-Silesian and Zaglebie Metrpolis, covering the western part of its territory. The company is undergoing the multiannual process of fleet replacement, justifying its investment decision with environmental factors, including emissions. The operator provided the author with the following data: consumption of diesel fuel depending on bus size and Euro emissions standards, consumption of power for charging electric buses, average daily and annual mileage. It facilitated the author to construct scenarios of annual transport work per vehicle and analyze the emissions respectively.
Findings: Electrification of public transport delivers positive environmental effects resulting in reduction of local emissions of pollutants and greenhouse gases. If the emissions of the source of power are included in the calculations, the benefits are lower, but it is possible to increase them by modification of the energy mix of supplied power, by significant increase of share of environmentally neutral or green energy.
Research limitations/implications: If possible, there could be conducted further research covering emissions related to production of diesel fuel and hydrogen (per unit), as no other fuels are practically in use.
Practical implications: Analyzed case provides the public transport operators with knowledge on their actual emissions and facilitates them to adjust the structure of the fleet in use to lower the environmental impact.
Originality/value: The paper addresses the issue of zero-emission transport. Originality of the approach results from inclusion of the environmental effects of power generation source in the environmental effects of electrification of fleet in public transport.
Keywords: public transport emissions, electromobility, electric bus, hybrid bus, diesel bus.
Category of the paper: research paper.

1. Introduction and literature review

Massive electrification of public transport, however sometimes considered as controversial, is one of the central areas of interest and investment carried out on European, national and local level. Transport sector, including public transport is one of the major sources of pollution, noise and greenhouse gases on densely developed urban areas, so lowering its negative impact on quality of life and health of the inhabitants of the cities plays a vital role in public policy. Since year 2007 European policy has been concentrated around reduction of emissions and consequently, major financial streams have been diverted to investments in low-emission fleet, alternative fuels, as well as changing the habits of the citizens, encouraging them to swap their private cars with unimodal or multimodal public transport, as well as with micromobility solutions (i.e. scooters, bicycles, e-bikes or walking) (Bachanek, 2020). Polish practice in greening of public transport is basically founded on the Act of 11.01.2018 of Electromobility and Alternative Fuels (AEAF), which defines the framework and milestones that are supposed to me achieved in terms of share of zero- and low-emission vehicles circulating in the cities and in intercity connections (Act of Electromobility and Alternative Fuels of 11 January 2018 with amendments, 2018).

This legislation provides also clarification on the definition of a "zero-emission bus". Based on the general definition of a "bus" as a motor vehicle designed to carry more than 9 people, including the driver, the term "zero-emission bus" is restricted to vehicles that meet specific technical criteria. Only those vehicles that are powered by:

- electricity generated from hydrogen fuel cells, or
- engines whose life cycle does not result in the emission of greenhouse gases or other substances covered under the greenhouse gas emissions management system,

are considered zero-emission buses.

Therefore, the legislation excludes diesel-powered vehicles, which have been the predominant type in public transport fleets, as well as vehicles increasingly found in such fleets - those with liquid or compressed natural gas (LNG/CNG) or hybrid powertrain.

AEAF also established new obligations for local governments. These include the following requirements:

- they must ensure that electric vehicles make up at least 30% of their total fleet (excluding service vehicles used by the utility sector),
- for other public tasks (excluding public transport), local authorities are required to use electric or gas-powered vehicles, with the number of such vehicles equaling or exceeding 30% of all vehicles used for these tasks, or to commission a third party to perform these tasks with a fleet that meets the same criterion.

Local governments must either directly provide or contract urban public transport services from an entity whose fleet contains at least 30% zero-emission buses (Pietrzak, Pietrzak, 2020).

The AEAF also outlined a gradual increase in the proportion of zero-emission buses in the public transport fleet, with the following target milestones:

- 5% by the end of 2020,
- 10% by the end of 2022,
- 20% by the end of 2024,
- 30% by the end of 2027.

Another factor affecting mobility in the cities is traveling habit of the people. The indicator of motorization for some EU countries is high, so it means that their citizens may demonstrate high reluctance to changing their mobility habits. The number of cars per 1000 inhabitants for EU member states is provided in fig. 1.

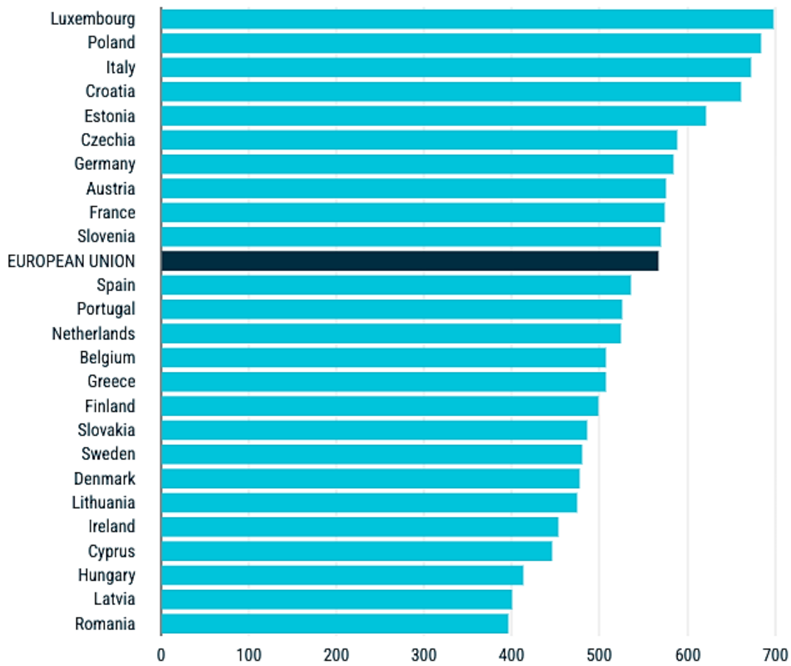


Figure 1. Motorization rate in the EU for year 2021.

Source: European Automobile Manufacturers' Association.

All the aforementioned activities should result in improvement of the air quality, lowering the congestion and making a city more comfortable and livable place.

According to the statistics provided by the European Environment Agency, Poland is one of the countries with the highest CO_2 emission from transport, reaching the level of 136,8 g/km, comparing to the EU average of 110 g/km (Sustainability of Europe's mobility systems, 2024).

ACEA (European Automobile Manufacturers' Association) data confirm, that there can be observed a declining trend of sales of new diesel buses, and growth of sales of electric ones (EVs). The share of hybrid and other (natural gas and hydrogen) fueled buses remains stable, as presented in fig. 2.

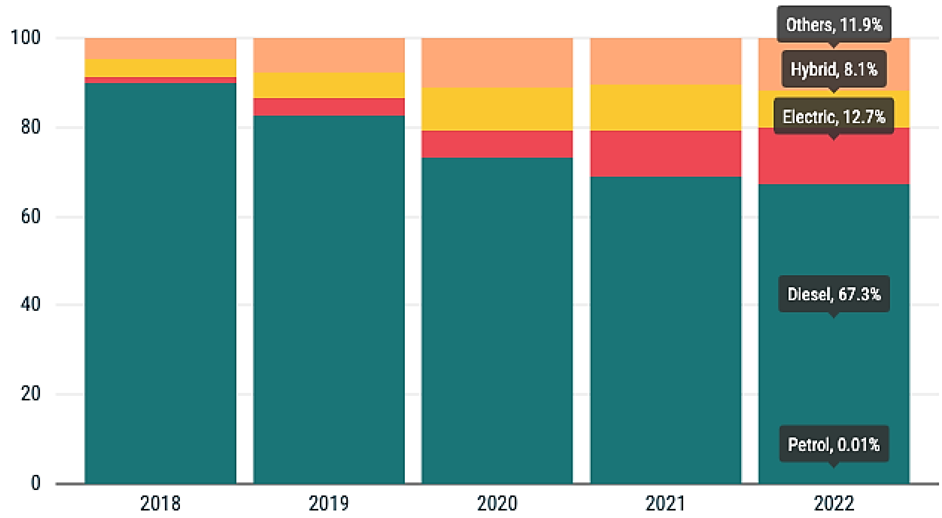


Figure 2. Structure of sales of new buses in years 2018-2022.

Source: European Automobile Manufacturers' Association.

According to the ACEA report *Vehicles in Use 2023*, in the EU only 1,4% of bus fleet is EV, 1,8% hybrid-electric (HEV), and 3,9% natural gas fueled (LNG, CNG or LPG). The share of hydrogen-powered fuel-cell vehicles (FCEV) is not revealed (ACEA Report - Vehicles on European roads, 2024).

Electromobility may become a critical factor of sustainable and eco-friendly mobility in the future, contributing to the reduction of air pollution and greenhouse gas emissions. Reduction of local emissions of air pollution by EVs or FCEVs is particularly important in urban areas because they are characterized by high population density and heavy traffic. It is therefore assumed that e-mobility and H_2-mobility may become the dominant technologies applied in future mobility in urban agglomerations.

For the needs of public policy, it is assumed that EVs are considered to be zero-emission and climate neutral during their operations. Naturally, this approach does not take into account the whole product life cycle, energy and material consumption required on all stages of its economic and operational life as well as manufacturing-derived carbon footprint. In order to create a more comprehensive image of consequences of public transport electrification on its operational stage of the life cycle of the vehicles and following the tendency of internalization of costs, the external costs of emissions to the environment related with power generation and distributions should be also taken into overall account, as they may seriously affect the economic rationale of electrification of public transport. The differentiation of economic costs will be also dependent on the energy mix of particular place, e.g. a country or an area having specific sources of electricity.

There are different measures undertaken by the administration to reduce traffic congestion and improve the environmental conditions in the city, particularly in terms of climate and pollution issues, among which there can be identified:

- pedestrianization of areas in the city (Pooley et al., 2013; Song et al., 2017),
- creation of car-free zones (Ellison et al., 2013),
- creation of clean transport zones (Heijlen, Crompvoets, 2017),
- introduction of low- and zero-emission vehicles (Kendall et al., 2017; Ranaei et al., 2016),
- construction of multimodal changing centers, park and ride or kiss and ride facilities,
- construction of dedicated bus lanes available also for individual electric vehicles,
- fiscal legislation promoting low- and zero-emission vehicles.

Combination of the aforementioned activities shall lead to significant improvements in terms of pollutants and GHGs emissions locally, however, investigation results of the overall general effects of pro-environmental projects are still yet to be published. This paper provides a part of such analysis, where only electrification of fleet on selected bus line was taken into consideration. Using differential approach there was conducted an analysis comprising emissions of pollutants, GHGs specific for combustion powertrains, emissions of the source of power taking into account current energy mix of the country, and – basing on them – there was calculated an environmental net effect of electrification. Having these values, they were subject to monetization in order to determine the economic benefits and costs of powertrain transformation of the fleet in public transport (Pietrzak, Pietrzak, 2021).

2. Materials and methods of the paper

The research was conducted in several stages. Stage 1 consisted of collection and analysis of literature and reports on development of electromobility, respective legislation and policies. Delivery of public transportation services is a legal duty which must be fulfilled by the local and regional government. In case of Upper-Silesian Metropolitan Area, the entity responsible for this service is Upper-Silesian and Zagłębie Metropolis, with is subsidiary Urban Transport Authority. This organization provides planning, coordination and financing for public transportation and the services are rendered by the operators (carriers) basing on contracts. Urban Transport Authority defines also the minimum requirements concerning fleet used by the operators on different lines, including equipment, powertrain and emissions of the buses. In this case the operators must observe these requirements, but may use the fleet of the higher standard of emissions or equipment.

For this article there were selected two bus lines: A4 and 676, connecting different parts of the municipality of Gliwice, which were subject to electrification in year 2021. The analysis which was carried out in this paper is of the what-if type, where consumption of fuels and power was taken from the real operations of the operator – Urban Transport Company in Gliwice. Considered the emission standard of the withdrawn diesel fleet and its replacement with EVs, there were calculated appropriate emissions which later were subject to monetization.

Stage 2 comprises projection of volumes of transportation work carried out annually on A4 and 676 bus lines and estimation of emissions basing on measured consumption of diesel fuel and actual consumption of electricity registered by the company. Consequently, there were calculated the emissions of pollutants and GHGs of the power supply per kilometer, taken into account the energy mix.

Stage 3 provides comparison of three approaches, namely use of diesel-fueled vehicles vs. EVs excluding emissions at source vs. EVs including emissions of the source. Based on these calculations, monetary unit values of emission are applied to determine environmental economic costs and benefits of respective solutions. Considered the economic and technical life cycle of the vehicles, 10 years period of analysis was applied. For making comparisons of respective approaches, NPV method was used to aggregate the costs and benefits and express them in present values.

3. Operational aspects of analyzed case of electrification of bus lines

Both analyzed bus lines – A4 and 676 operate on densely urbanized areas of the city of Gliwice in Upper-Silesian Metropolis. The first line facilitates changes for the passengers from the tramway to reach the center of the city. Due to high intensity of arrival of passengers, the line operates every 10 minutes in the peak periods of the day and every 15 minutes besides during the week and every 20 minutes during the weekends. Line number 676 operates every 40 minutes and connects northern and southern residential neighborhoods of Gliwice. The diagrams of the lines are provided in figures – fig. 3 for line A4, fig. 4 for 676.

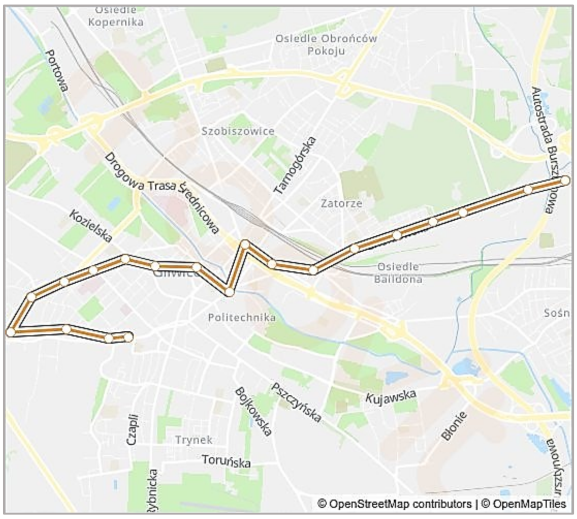


Figure 3. Network diagram of line A4.
Source: own elaboration, OpenStreetMap.

Exploitation work expressed in vehicle-kms is provided in the tables below. The abbreviations BN and CN define sizes of the vehicles, where BN stands for standard 12 meter 2-axis vehicle and CN stands for high capacity 18 meter 3-axis vehicle. Operations on line A4 are provided in table 1.

Table 1.
Operations of A4 bus line in years 2021-2024

Exploitation work in vehicle-kilometers for respective years								
A4	2021		2022		2023		2024	
	BN	CN	BN	CN	BN	CN	BN	CN
Jan	34 553,70	10 413,20	30 762,10	18 969,70	40 489,20	11 090,80	39 954,60	10 267,30
Feb	31 434,00	10 920,00	33 420,30	10 634,90	37 246,40	10 489,30	37 376,20	10 610,00
Mar	34 885,50	12 558,00	38 489,50	15 235,10	41 477,20	11 865,40	39 436,00	10 760,00
Apr	33 594,10	11 460,50	37 100,90	12 245,70	38 765,10	10 184,40	38 164,60	10 620,00
May	34 536,00	10 837,30	39 749,60	10 908,00	40 799,70	11 174,80	39 115,20	10 460,00
Jun	33 584,60	11 440,40	38 722,60	10 827,20	39 702,60	11 078,70	38 356,40	10 388,30
Jul	34 378,50	12 507,60	40 206,00	11 019,40	41 027,40	11 240,10	40 077,70	11 540,00
Aug	32 771,20	14 224,20	40 374,80	11 268,40	41 089,50	11 571,30	39 730,80	10 829,10
Sep	26 675,60	23 186,80	39 241,30	11 215,50	39 157,30	10 783,80	38 436,40	10 667,80
Oct	28 157,00	21 932,40	40 371,70	11 032,70	39 810,20	11 187,50	40 197,40	11 466,20
Nov	27 791,00	21 006,70	40 017,50	10 868,00	38 505,50	10 615,40	38 331,00	10 073,20
Dec	32 037,20	17 937,60	40 351,30	11 053,10	39 220,00	9 430,90	38 471,10	9 169,40
Tot.	384 398,40	178 424,70	458 807,60	145 277,70	477 290,10	130 712,40	467 647,40	126 851,30
	562 823,10		**604 085,30**		**608 002,50**		**594 498,70**	

Source: own elaboration.

Figure 3. Network diagram of line 676.

Source: own elaboration, OpenStreetMap.

Operations on line 676 are provided in table 2.

Table 2.
Operations of 676 bus line in years 2021-2024

Exploitation work in vehicle-kilometers for respective years								
A4	2021		2022		2023		2024	
	BN	CN	BN	CN	BN	CN	BN	CN
Jan	10 870,00	0,00	10 346,00	0,00	12 575,60	0,00	12 689,60	0,00
Feb	10 487,60	0,00	9 887,40	0,00	11 775,60	0,00	12 250,50	0,00
Mar	11 740,70	0,00	11 073,20	0,00	13 200,30	0,00	12 534,20	0,00
Apr	10 638,60	0,00	9 888,80	0,00	11 585,40	0,00	12 250,50	0,00
May	11 285,40	0,00	10 750,40	0,00	12 791,00	0,00	12 629,70	0,00
Jun	11 155,20	0,00	10 531,70	0,00	12 535,20	0,00	12 345,00	0,00
Jul	11 597,00	0,00	10 982,80	0,00	12 819,90	0,00	13 198,60	0,00
Aug	10 224,80	0,00	11 145,90	0,00	13 010,10	0,00	12 808,40	0,00
Sep	11 087,70	0,00	10 889,40	0,00	12 535,20	0,00	13 853,30	0,00
Oct	10 977,70	536,80	11 000,70	0,00	13 023,10	0,00	14 596,70	0,00
Nov	10 719,40	268,40	10 334,70	256,50	12 250,50	385,90	13 398,30	392,00
Dec	10 710,30	0,00	12 058,30	0,00	11 753,90	0,00	13 155,90	0,00
Tot.	131 494,40	805,20	128 889,30	256,50	149 855,80	385,90	155 710,70	392,00
	132 299,60		**129 145,80**		**150 241,70**		**156 102,70**	

Source: own elaboration.

Until the end June 2021 the lines were operated by combustion engines powered buses and in July 2021 all the vehicles were replaced by the EVs. A sample picture of the EV used by the operator is provided in the fig. 4 below.

Figure 4. Electric bus preparing for charging with a high power pantograph connection in the terminal station.

Source: PKM Gliwice sp. z o.o.

Depending on the emissions standard, fuel consumption of the vehicles differed. The details are provided in the table 3. Validity of given standard refers to the manufacturing date of given vehicle. The values are the average ones, measured by the operator in over 4 years of operations.

Table 3.
Consumption of diesel fuel depending on emission standard

`	Validity of the standard	Fuel consumption [dm^3/100 km]
Euro III	10.2000 - 10.2005	47,70
Euro IV	10.2005 - 10.2008	46,13
Euro V/ Enhanced Euro V (EEV)	10.2008 - 12.2012	50,40
Euro VI	from 2013	49,76

Source: own elaboration.

Approximate fuel consumption is used later to determine emissions of pollutants and GHGs to make comparisons of each standard with the electric powertrain of the buses.

4. Results of the research – environmental impact of electrification of the bus lines

Emissions of GHGs and pollutants to the atmosphere is a derivative of the emission standard met by given vehicle, fuel consumption and annual mileage. Given the figures for years 2021-2024, there was developed a projection of exploitation work that is anticipated to be delivered for years 2025-2030, covering average technical and economic life of an EV without the need to conduct major periodic repairs. Naturally, all workload-related repairs need to be conducted in order to maintain the fleet in required condition, however they are comparable in nature, independent from the powertrain.

The historic and projected exploitation work is provided in the figure below – fig. 5.

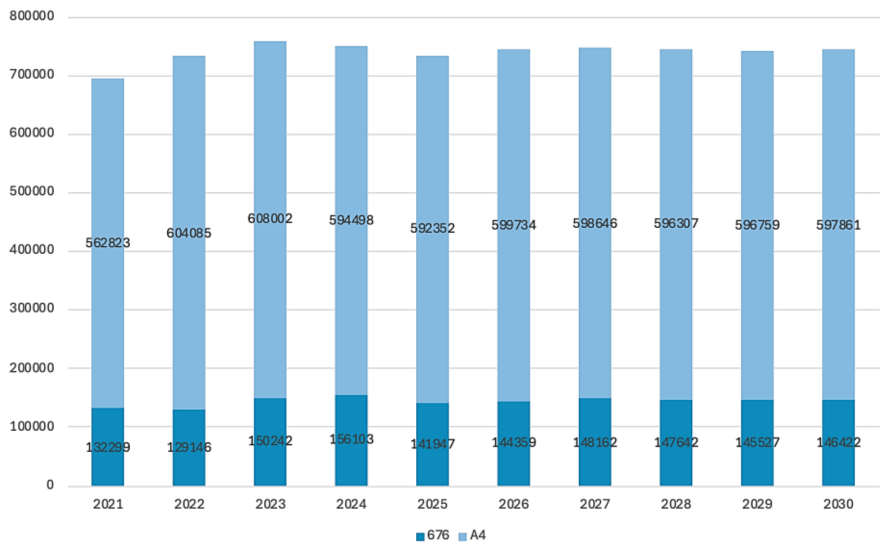


Figure 5. Historical and planned exploitation fork for lines A4 and 676.

Source: own elaboration of data provided by PKM Gliwice sp. z o.o.

Emissions specific for diesel fuels which are regulated by Euro standards cover: particulate matter (PM), hydrocarbons (HC) and non-methane volatile organic compounds (NMVOC), nitrogen oxides (NO_x), expressed in [g/kWh] of energy produced from the fuel. Given the physical and chemical features and constants of diesel fuel density of 0,84 kg/dm^3 and calorific value of 35,8 MJ/dm^3, there were calculated maximum emissions of the aforementioned pollutants per 1 dm^3 of consumed fuel as indicated in table 3. The values are provided in table 4 below.

Table 4.
Emission of pollutants based emission standard per kWh and consumed dm^3

Emissions standard	HC/NMVOC		NOx		PM	
	g/kWh	g/dm^3	g/kWh	g/dm^3	g/kWh	g/dm^3
Euro III	0,66	6,563	5	49,722	0,1	0,994
Euro IV	0,46	4,574	3,5	34,806	0,02	0,199
Euro V/ Enhanced Euro V (EEV)	0,46	4,574	2	19,889	0,02	0,199
Euro VI	0,13	1,293	0,4	3,978	0,01	0,099

Source: own elaboration.

For greenhouse gas (CO_2), its emission is independent from the emission standard, as it is constant and dependent only fuel consumption. Given the normative CO_2 equivalent emission per unit of fuel of 3169 kg CO_2eq/kg and the density of fuel, the emission per dm^3 equals 2662 kg CO_2eq.

In order to compare emissions of diesel fueled buses with the EVs, it is necessary to determine the emissions of sources of energy which is delivered to the operator. Taking into account current and future environmental policy of the central government in Poland, there was prepared a projection of the structure of energy mix until the end of year 2030, which is presented in the graph – fig. 6.

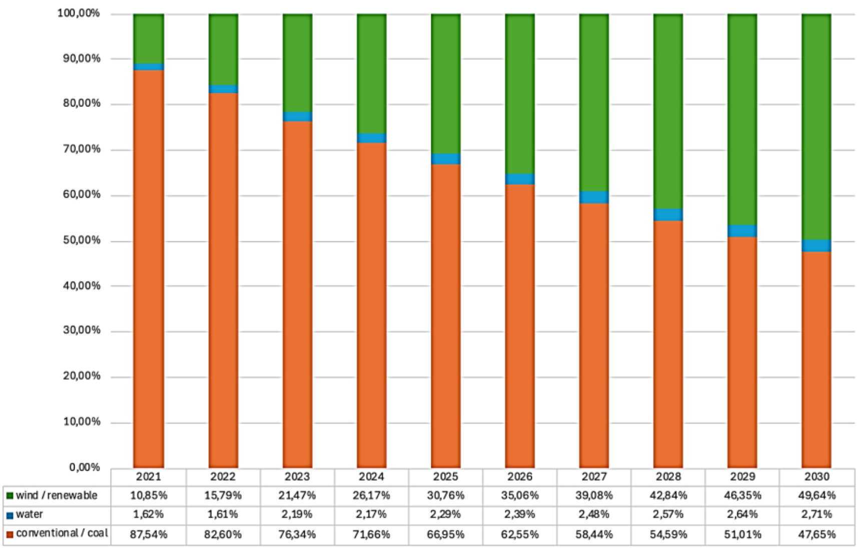


Figure 6. Projection of Poland’s energy mix up to 2030.

Source: own elaboration of data provided by the National Center for Emissions Management (KOBiZE).

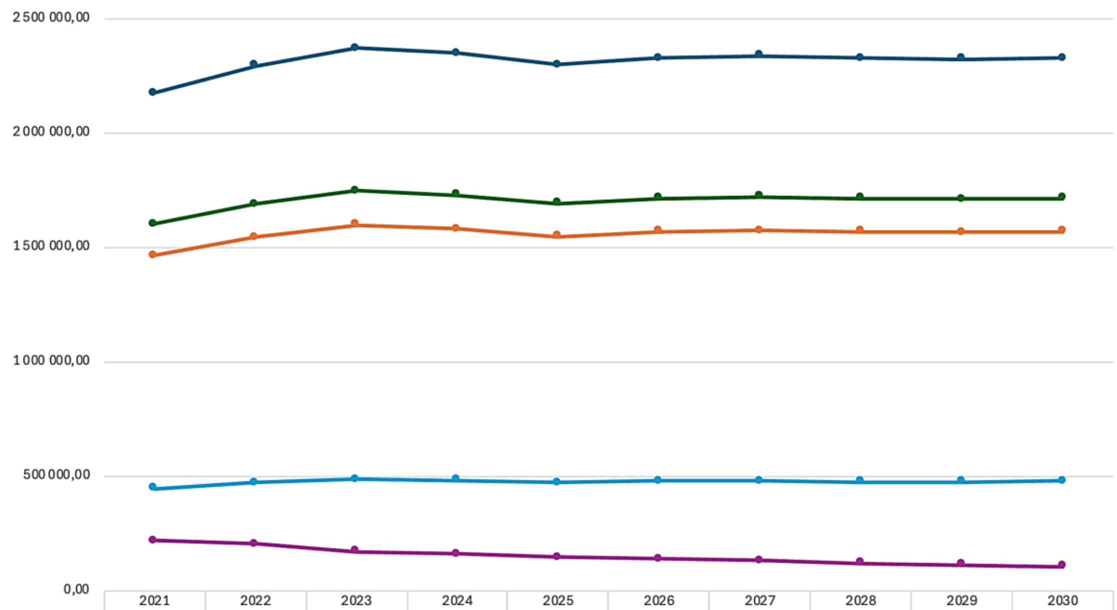
The emissions related to production of electricity was also determined based on the data provided by the National Center for Emissions Management (KOBiZE). For each individual year, this organization gathers data concerning total production of energy, regardless of the source or fuel and total registered emissions of pollutants and GHG. Historic and estimated emissions are presented in the table 5. As they refer to the whole sector of conventional power generation, in order to adjust emission assigned to final consumption of power, the values need to be multiplied by the share conventional power generation in country's energy mix. Since professional power generation sector maintains high level of investment in greening of their operations, the forecast of emissions is rather conservative.

Table 5.
Actual and forecasted emissions of conventional power generation in g/kWh

Component	Actual emissions			Forecasted emissions - *ceteris paribus*						
	2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
CO_2	761	788	733	733	733	733	733	733	733	733
NO_x	0,543	0,524	0,481	0,481	0,481	0,481	0,481	0,481	0,481	0,481
PM	0,022	0,021	0,018	0,018	0,018	0,018	0,018	0,018	0,018	0,018
HC/NMVOC	0,3	0,28	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25

Source: own elaboration of data provided by the National Center for Emissions Management (KOBiZE).

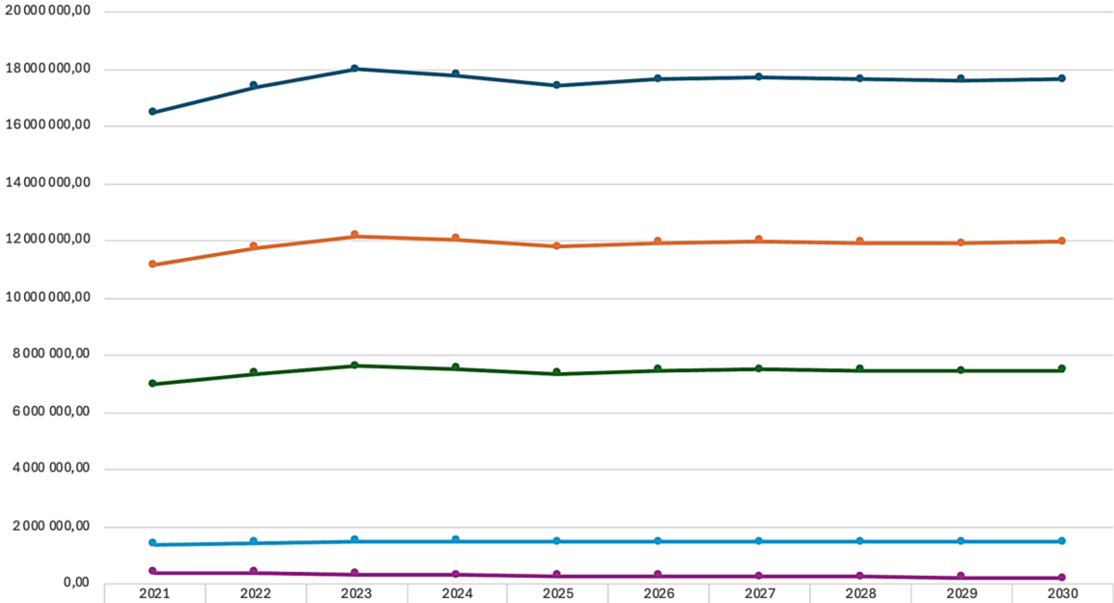
Given the consumption of fuel and power, there were calculated annual emissions of all pollutants and GHG for each class of vehicles meeting given Euro standard. All the classes (categories) of vehicles were mutually compared with EVs. Annual emissions generated by diesel fueled vehicles are provided in the figures below (Fig. 7-10).



	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Euro III	2 176 225,40	2 295 533,62	2 373 842,07	2 349 914,06	2 298 877,22	2 329 539,40	2 338 039,27	2 329 088,57	2 323 882,20	2 330 134,23
Euro IV	1 466 840,34	1 547 257,62	1 600 039,83	1 583 911,64	1 549 511,30	1 570 178,52	1 575 907,69	1 569 874,65	1 566 365,40	1 570 579,45
Euro V/EEV	1 602 617,67	1 690 478,74	1 748 146,71	1 730 525,62	1 692 941,03	1 715 521,29	1 721 780,78	1 715 189,30	1 711 355,22	1 715 959,34
Euro VI	447 162,41	471 677,40	487 767,92	482 851,28	472 364,43	478 664,77	480 411,30	478 572,14	477 502,36	478 787,00
EV	219 054,84	203 510,20	173 651,83	161 364,23	147 482,01	139 624,39	130 921,51	121 846,54	113 581,94	106 400,60

Figure 7. Projection of emissions of HC/NMVOC [g/year].

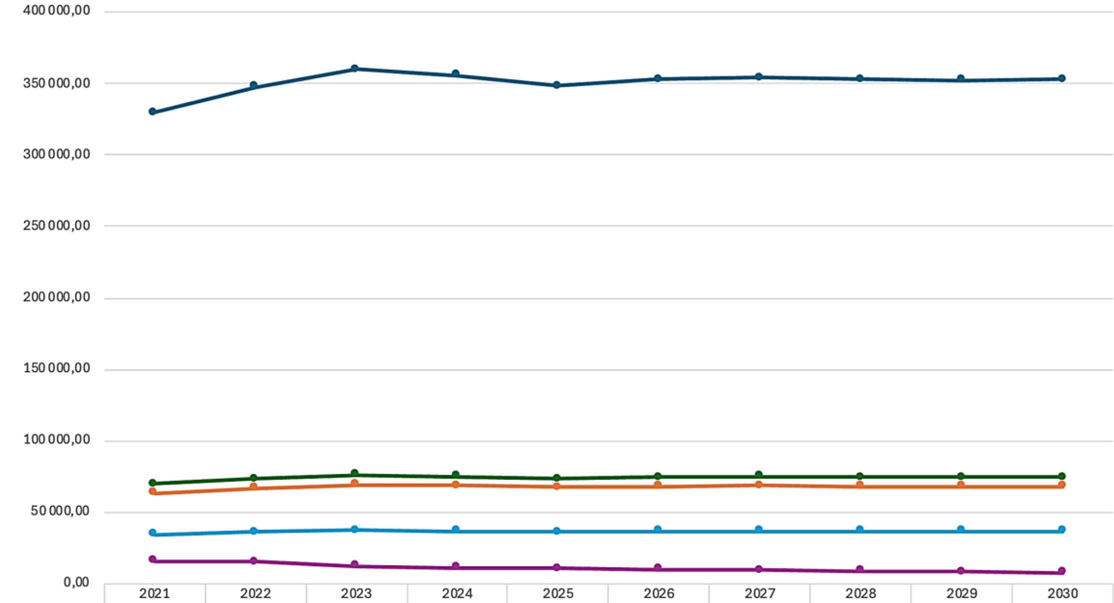
Source: own elaboration.



	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Euro III	16 486 556,04	17 390 406,24	17 983 652,07	17 802 379,22	17 415 736,53	17 648 025,73	17 712 418,74	17 644 610,41	17 605 168,21	17 652 532,05
Euro IV	11 160 741,74	11 772 612,33	12 174 216,12	12 051 501,62	11 789 759,92	11 947 010,46	11 990 601,96	11 944 698,42	11 917 997,62	11 950 061,06
Euro V/EEV	6 967 902,93	7 349 907,54	7 600 637,86	7 524 024,42	7 360 613,18	7 458 788,23	7 486 003,39	7 457 344,78	7 440 674,86	7 460 692,79
Euro VI	1 375 884,32	1 451 315,08	1 500 824,36	1 485 696,25	1 453 429,01	1 472 814,69	1 478 188,61	1 472 529,67	1 469 238,02	1 473 190,77
EV	396 489,26	380 854,80	334 106,13	310 464,78	283 755,38	268 637,33	251 892,99	234 432,74	218 531,65	204 714,76

Figure 8. Projection of emissions of NO_X [g/year].

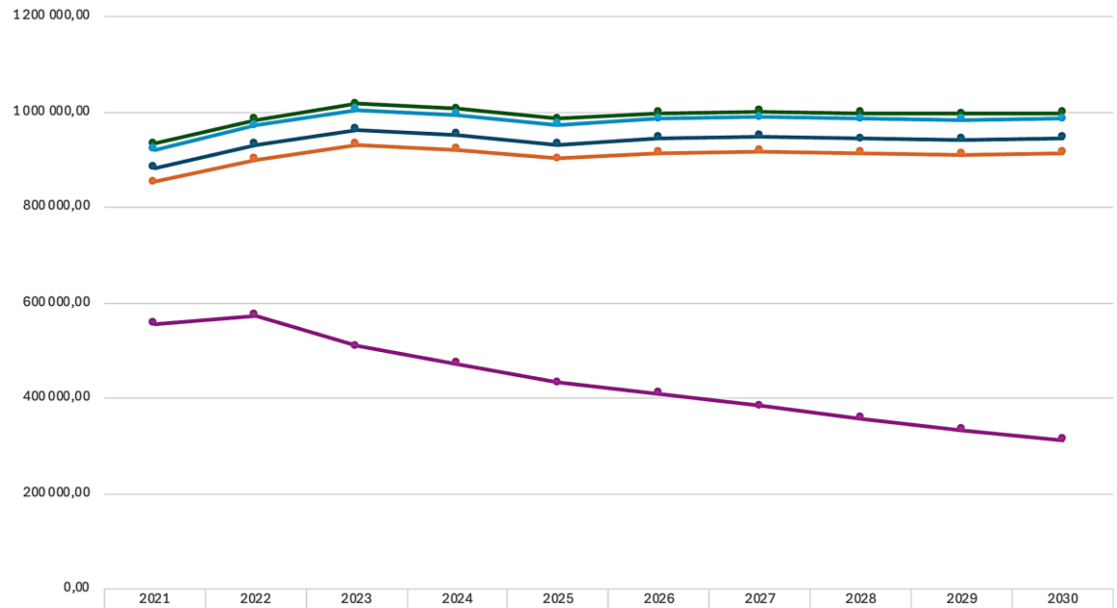
Source: own elaboration.



	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Euro III	329 731,12	347 808,12	359 673,04	356 047,58	348 314,73	352 960,51	354 248,37	352 892,21	352 103,36	353 050,64
Euro IV	63 775,67	67 272,07	69 566,95	68 865,72	67 370,06	68 268,63	68 517,73	68 255,42	68 102,84	68 286,06
Euro V/EEV	69 679,03	73 499,08	76 006,38	75 240,24	73 606,13	74 587,88	74 860,03	74 573,45	74 406,75	74 606,93
Euro VI	34 397,11	36 282,88	37 520,61	37 142,41	36 335,73	36 820,37	36 954,72	36 813,24	36 730,95	36 829,77
EV	16 064,02	15 263,26	12 502,93	11 618,22	10 618,70	10 052,96	9 426,35	8 772,95	8 177,90	7 660,84

Figure 9. Projection of emissions of particulate matter [g/year].

Source: own elaboration.



	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Euro III	882 634,58	931 023,67	962 784,05	953 079,31	932 379,77	944 815,75	948 263,13	944 632,90	942 521,30	945 057,00
Euro IV	853 583,50	900 379,91	931 094,93	921 709,62	901 691,38	913 718,04	917 051,96	913 541,21	911 499,11	913 951,35
Euro V/EEV	932 595,03	983 723,12	1 017 281,26	1 007 027,20	985 155,98	998 295,88	1 001 938,40	998 102,69	995 871,56	998 550,79
Euro VI	920 752,55	971 231,40	1 004 363,40	994 239,55	972 646,06	985 619,11	989 215,38	985 428,37	983 225,57	985 870,78
EV	555 669,11	572 735,85	509 147,18	473 119,92	432 417,25	409 378,72	383 861,88	357 254,05	333 022,24	311 966,56

Figure 10. Projection of emissions of CO_2 [kg/year].

Source: own elaboration.

Given the calculated emissions, it is possible to determine avoided emissions related to electrification of the public transport fleet. For the time horizon of 10 years, the environmental benefit for replacement of diesel fueled buses with the EV is presented in the table below – table 6.

Table 6.
Total 10-year-avoided emissions resulting from electrification of public transport fleet

Component of the exhaust	Euro III	Euro IV	Euro V/EEV	Euro VI
HC/NMVOC [kg]	21 627,64	14 083,03	15 527,08	3 238,32
NO_x [kg]	172 457,61	115 815,32	71 222,71	11 749,23
PM [kg]	3 396,67	568,12	630,91	255,67
CO_2 [Mg]	5 048,62	4 739,65	5 579,97	5 454,02

Source: own elaboration.

5. Discussion of the results – economic outcome of electrification of the bus lines

For projects which are unlikely to generate financial profit and positive financial rate of return, it is necessary to determine the economic outcome. It may either improve or deteriorate the welfare of given community affected by their execution. From the financial point of view, public projects are seldom characterized by positive rates of return and profitability. They rather require financial transfers in order to secure continuous delivery of given public service. However, apart from financial outcome, there must be assessed their economic impact, as environmental benefits directly and indirectly affect welfare of the people.

For this reason the Center for European Transportation Projects periodically publishes unit costs assigned to given environmental effects of their implementation. In this case avoidance of emissions may be considered as a benefit. Unit costs of emissions for the 10 year period are provided in the table below – table 7.

Table 7.
Unit costs of emissions – current prices

Component of the exhaust	**2021**	**2022**	**2023**	**2024**	**2025**
HC/NMVOC [PLN/kg]	2 536,86	2 814,12	3 364,12	3 753,65	3 856,54
NO_x [PLN/kg]	53 274,15	59 096,59	70 646,61	78 826,68	80 987,26
PM [PLN/kg]	1 021 993,94	1 133 689,76	1 355 261,59	1 512 185,36	1 553 633,11
CO_2 [PLN/Mg]	188,61	204,51	210,20	215,88	221,56
Component of the exhaust	**2026**	**2027**	**2028**	**2029**	**2030**
HC/NMVOC [PLN/kg]	3 980,94	4 100,12	4 201,61	4 305,97	4 410,12
NO_x [PLN/kg]	83 599,72	86 102,48	88 233,73	90 425,40	92 612,50
PM [PLN/kg]	1 603 749,80	1 651 761,81	1 692 647,08	1 734 691,36	1 776 647,96
CO_2 [PLN/Mg]	227,24	232,92	238,60	244,28	249,96

Source: Center of European Transportation Projects.

To determine the value of benefits resulting from electrification of the public transport fleet, it is necessary to calculate annual benefits and aggregate it. The most useful method for this is the Net Present Value approach, taking into account the changes of value of money in time. As advised by the European Commission, the interest rate applied for calculations of economic NPV (ENPV) must equal 3%. Comparison of economic effects of electrification of fleet are provided in the table 8.

Table 8.
Environmental economic benefits of electrification of fleet [PLN]

Economic value of avoided emissions	**Euro III**	**Euro IV**	**Euro V/EEV**	**Euro VI**
ENPV HC/NMVOC	70 216,19	45 758,88	50 440,04	10 603,67
ENPV NO_x	11 743 946,01	7 887 991,40	4 852 324,88	803 635,10
ENPV PM	4 439 129,93	745 217,66	827 210,73	337 172,56
ENPV CO_2	1 062 786,10	923 510,09	1 087 341,64	1 062 786,10
Total ENPV	**17 316 078,23**	**9 602 478,04**	**6 817 317,29**	**2 214 197,43**

Source: own elaboration.

It may be concluded, that regardless of choice of emission standard of the buses to be withdrawn from circulation, there will be generated environmental benefit of various scale. However, according to the legislation mentioned in the introductory part, EVs are considered to be zero-emission, which is only partially true. Unless they generated any environmental costs, as they should be, according to the law, ENPV of these costs should equal zero. As it was confirmed earlier in the text, power generation is not absolutely zero-emission, so taking into consideration the emissions of powerplants and the consumption of energy by EVs for traction, the actual economic costs are the following, as presented in the table below – table 9.

Table 9.
Annual economic costs of emissions at source for EVs – current prices [PLN]

Component of the exhaust	2021	2022	2023	2024	2025
HC/NMVOC	555,71	572,70	584,19	605,71	568,77
NO_x	21 122,63	22 507,22	23 603,47	24 472,91	22 980,57
PM	16 417,33	17 303,81	16 944,74	17 568,91	16 497,57
CO_2	104 803,22	117 132,68	107 020,33	102 135,34	95 805,14
Component of the exhaust	**2026**	**2027**	**2028**	**2029**	**2030**
HC/NMVOC	555,84	536,79	511,95	489,08	469,24
NO_x	22 458,01	21 688,61	20 684,88	19 760,81	18 959,15
PM	16 122,43	15 570,08	14 849,51	14 186,13	13 610,62
CO_2	93 026,45	89 408,75	85 240,83	81 351,00	77 979,77

Source: own elaboration.

Economic NPV of costs these emissions is the following:

- HC/NMVOC - 4 813,04 PLN,
- NO_X - 192 521,96 PLN,
- PM - 140 576,24 PLN,
- CO_2 - 846 407,80,
- Total ENPV: 1 184 319,04 PLN.

So, using the legislators reasoning, total ENPV of environmental costs of zero-emission buses should equal 0, which actually is not true. As it was confirmed, ENPV of actual environmental costs generated by electrification of fleet during 10 years equals almost 1,2 millions of PLN. What should be noticed and underlined, is the fact that increase of share of green energy in the energy mix (e.g. renewable – wind, solar, water) and decline of conventional sources improves the environmental efficiency of electrification projects and in the extreme case, where the whole demand for power is covered by zero-emission sources, annual and aggregated environmental costs may equal 0.

Conclusions

Policy makers put strong emphasis on implementation of green solutions in public transport. Legislators defined strict regulations related to the share of zero-emission fleet which must be used for delivery of public services, still the overall environmental effect of electrification of vehicles is strongly affected by the energy mix of given country. In order to cut the emissions effectively, it is necessary to readjust it and increase significantly the share of renewable sources of energy, or – at least – environmentally neutral sources of energy. Purchase of EVs may lead to achievement of the electromobility objectives defined on a national level, however, the overall benefit of greening the fleet will be disturbed by constantly high share of conventional powerplants in supplies of energy. In such case the emissions will take place, but elsewhere in terms of location, so then the positive environmental effect is dubious. Regardless of all, withdrawal of diesel-fueled vehicles and their replacement with EV, excluding the investment outlay, is economically and environmentally profitable, but the scale of this benefit is highly dependent on the condition and emission standard of the liquidated fleet.

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(IN)FORMAL COMMUNICATION SATISFACTION OF IT TOOLS AS AN ELEMENT OF ORGANIZATIONAL RESILIENCES

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Purpose: The aim of this study is to investigate whether IT tools influence the assessment of communication satisfaction during remote work to support organizational resilience after crisis.
Design/methodology/approach: The research tool was a CATI questionnaire carried out on 700 respondents, data were obtained in 2022 when the crisis was in the blooming phase. The questionnaire was expanded Communication satisfaction Questionnaire CSQ (Dawn and Hazen 1977) to include assessing satisfaction with the use of IT communication tools – synchronous (on-line) or asynchronous (off-line), in formal and informal organizational communication.
Findings: Respondents confirmed positive assessment of IT tools in communication during remote and hybrid work. Assessments of formal and informal communication in synchronous and asynchronous modes were above average. women better asses the IT tool in case of all types of communication while remote or hybrid work.
Research limitations/implications: More than 70% of respondents in our survey were young people born after 1980 it may have affected the level of satisfaction from IT communication. The tools themselves and how they were implemented were not studied here in order to asses if the user experience affected the results (the tool itself is satisfactory). These might be the suggestions for future research. The research is limited to respondents from Poland, which may affect the judgement because of high level of digital transformation of the country.
Practical implications: The communication while crisis facilitates and ensures business continuity and organization resilience. Employees satisfies with IT tools they use for communication support to overcome the crisis. Research findings can help managers identify key areas where organizational employees experience is valuable for the organization resilience in case of future crises.
Originality/value: The originality of the conducted research lies in presenting the new information about communication satisfaction from IT tools during remote work to support organizational resilience after crisis.
Keywords: communication satisfaction, IT tolls, hybrid work, remote work, resilience.
Category of the paper: Research paper.

1. Introduction

The management of crises has become a topic of concern for both academics and practitioners for some time, but interest in this field has grown significantly in recent years, and not without reason. Disruptions appear to be both inevitable and unpredictable. As a result, much of the literature suggests that investing in resilience may be a more effective strategy than allocating limited resources toward controlling the environment or defending against specific risks (Wildavsky, 1988). Resilience refers to an organization's preparedness to absorb shocks efficiently from an operational standpoint (Walker et al., 2004). From an individual perspective, it focuses on analyzing the cognitive and behavioral mechanisms that support adjustment to new situations (Biggs et al., 2010). Regardless of their origin, crises are often surprising, unpredictable, and demand a swift response, along with effective internal and external communication.

In this paper, resilience is understood as "the ability to repair old practices and develop new practices when the old ones are no longer possible" (Mark et al., 2009, p. 690). Therefore, organizational resilience can be viewed either as a response to crises or as a lesson learned over time, where new challenges serve as triggers for its application (Sutcliffe, Vogus, 2003). Communication during a crisis facilitates, and even ensures, business continuity, which in turn serves as the foundation for organizational resilience (Meechang, Watanabe, 2022; Steen et al., 2024).

Since the beginning of the 21st century, crisis management scholars have primarily focused on crisis communication, particularly its external aspects (Johansen et al., 2012). However, several studies have demonstrated that employee behavior during a crisis is crucial, and that internal communication and crisis management are the driving forces behind positive organizational outcomes (Ecklebe, Löffler, 2021; Frandsen, Johansen, 2011; Mazzei, Ravazzani, 2015; Taylor, 2010). The crisis management literature consistently highlights that employees are key to an organization's ability to recover after a crisis (Mohamad et al., 2023).

It can be argued that the quality and quantity of communication directly impact the level of employee trust and commitment (Adamu, Mohamad, 2019a). Despite this, there remains a gap in assessing employee satisfaction with communication, particularly across its different types and modes. Furthermore, the effectiveness of crisis communication strategies has received mixed support in research, calling for further investigation (Nöhammer et al., 2023; Tkalac Verčič et al., 2019). Additional research into communication satisfaction is essential, as its relationship to business continuity and effectiveness remains unclear.

Crisis communication is complex due to the speed, volume, sources, and channels of information exchanged, which can overwhelm individuals over time. Despite the confusion, signs of resilience often emerge, to which employees may refer. In the literature, entrepreneurial resilience is considered a multilevel concept (Doerfel et al., 2022), typically classified into three levels: individual, team, and organizational (e.g., Raetze, 2021), or individual, organizational, and interorganizational resilience (e.g., Doerfel et al., 2022). This paper focuses on individuals within organizations, as emphasized in the aforementioned studies. These same levels can also be applied to communication.

At the individual level (Doerfel et al., 2010), people connect and assist one another, often coordinating through social media and other channels. These actions underscore the importance of communication in fostering resilience. Moreover, resilient employees are able to accept adverse situations and make efforts to adapt to changing environments through effective communication (Agarwal, Buzzanell, 2015). They cultivate resilience through storytelling, routines, and networking, which help legitimize negative experiences (Buzzanell, 2018). Employees can further build resilience by activating organizational connections and developing social support networks across various levels (Lee et al., 2020).

Organizational resilience is not merely the sum of individual-level resilience (Kantabutra, Ketprapakorn, 2021); rather, it is built upon processes that promote competence, restore efficacy, and encourage growth (Raetze et al., 2021). Organizational resilience is a capacity that emerges across multiple levels (Tasic et al., 2020). Recognizing employees as key stakeholders is a critical first step toward successful crisis management. In this context, Mazzei and Ravazzani (2013) view internal communication as a vital component, acting as a lever to either prevent crises or support appropriate responses, thus minimizing damage and producing positive outcomes. Effective communication can mitigate the impact of crises on organizations and their workforce—for example, by enabling employees to work independently (Kim, 2020; Lengnick-Hall et al., 2011).

In critical situations—whether due to a hurricane, pandemic, or flood—communication becomes the foundation for the survival and functioning of the organization. With significant employee participation, organizations can develop the communication mechanisms necessary to navigate through such cataclysms. If these mechanisms prove satisfactory for the participants involved, they can serve as a model for future crisis communication and be applied to unforeseen events.

Both formal and informal communication channels must meet the needs of employees to be effective. Formal communication enables the efficient and rapid management of the organization during a crisis, supporting its core operations and facilitating the exchange of messages with external stakeholders, such as clients and suppliers. Informal communication, on the other hand, plays a key role in fostering relationships among employees during crises. The pandemic, for instance, highlighted the importance of human connection within organizations. The disruption of pre-existing informal networks hindered the organization's basic functioning, emphasizing the need to maintain strong interpersonal relationships, even during a crisis.

In today's world, intra-organizational crisis communication is largely facilitated by IT tools. Employees use the tools available within the organization for formal communication, while often shifting informal communication to platforms outside of the company's systems. Since the value of a technology lies in how it is used rather than the technology itself (Orlikowski, 2000), new or adapted routines may be created by employees to meet their own satisfaction needs. In response to crises, employees often alter both communication and technology structures, using available tools to gain access to the necessary resources and contacts for survival and recovery (Sutton et al., 2008). They may also adapt one or more ICT technologies (Katz, Rice, 2002) that they have access to and use these technologies to facilitate recovery. This research, therefore, focuses on communication satisfaction via IT tools.

The communication tools were categorized based on the time dimension in which the communication process occurs—either synchronous or asynchronous (Zalewska-Turzyńska, Miklaszewska, 2019). At both the individual and organizational levels, ongoing crisis communication is also intertwined with issues such as exertion, overload, and fatigue (Lu, Jin, 2022). Communication overload is one of the identified challenges associated with the increased workload from remote work (Nadler, 2020; Lee et al., 2021). Therefore, the issue of satisfaction with organizational communication re-emerges in this paper, now considered in the context of avoiding communication overload.

IT communication tools enable remote work, and the level of satisfaction with these tools can help prevent overload, thus supporting the recovery process. Given the constant evolution of IT tools and the recurrence of crisis situations, ongoing research on communication satisfaction is both relevant and necessary.

The aim of this study is to investigate whether IT tools influence the assessment of communication satisfaction during remote work. To evaluate communication satisfaction, the Communication Satisfaction Questionnaire (CSQ) developed by Downs and Hazen (1977) was utilized. The original CSQ was developed in two phases: initially, 7 dimensions were identified, but the final version of the questionnaire was refined to 40 items, with five items for each of the 8 factors. These items are measured on a 7-point Likert-type scale, ranging from "extremely satisfied" to "extremely dissatisfied." The test-retest reliability of Downs and Hazen's questionnaire was reported to be 0.94, demonstrating the strong consistency and stability of its factor structure (Tkalac Verčič et al., 2007).

Additionally, Gray and Laidlaw (2004) confirmed that the CSQ has gained widespread use in scholarly research, and it has been analyzed by various other researchers (a comprehensive list of studies and comparisons can be found in Meintjes, Steyn, 2006).

However, there have been some criticisms of the CSQ, particularly regarding the validity of its original 8-factor structure. Tkalac Verčič et al. (2021) questioned the validity of the factor structure, and Deconinck et al. (2008) also raised concerns. In response to these concerns, alternative factor solutions have been suggested by researchers: a 5-factor solution has been proposed as more valid than the original 8-factor model (Deconinck et al., 2008), while others have suggested a 6-factor solution (Greenbaum et al., 1988) or even a 9-factor solution (Pincus, 1986).

In this study, the revised questionnaire structure proposed by Deconinck et al. (2008) has been adopted, focusing on the following dimensions:

- Co-worker Communication: This dimension assesses the extent to which horizontal and informal communication among employees is accurate, open, and free-flowing.
- Supervisor Communication: This factor measures two-way communication with supervisors, focusing on consultative and participative communication styles.
- Media Quality: This dimension evaluates the quality of meetings, organizational directives, and other formal communication channels.
- Corporate Information: This covers broad organizational information, such as updates on the company's financial health and changes within the organization.
- Organizational Integration: This factor examines the degree to which employees receive feedback about their immediate work environment and their role within it.
- Communication Climate: This dimension looks at the overall communication environment, both at personal and organizational levels. It assesses how well the communication climate encourages employees to meet organizational goals and shapes their attitudes toward the company.
- Personal Feedback: This refers to how employees are evaluated, particularly in terms of performance appraisal and constructive feedback.
- Subordinate Communication: This dimension focuses on two-way communication between supervisors and their subordinates. Only supervisors respond to this category, as it evaluates their communication with those they manage.

Media is usually distilled down to a categorization of “traditional” versus “advanced” technologies (Carr, Kaynak, 2007). Therefore we have broaden the questionnaire by the purpose of the tools – for formal and for informal communication.

2. Method

The research method was designed with 5 consecutive steps:

1. CSQ questionnaire analysis.
2. Expanding the CSQ questionnaire to include a general construct related to assessing satisfaction with the use of IT tools – synchronous, that is simultaneously (on-line) or asynchronous with a delay (off-line), tools for communication and tools supporting the exchanging information for the formal or informal purposes.
3. Data collection.

4. Examining the relationship of the impact of the new construct on communication satisfaction.
5. Exploring perceptions of different forms and types of communication.

Critical review of CSQ questionnaire analysis literature

The study was conducted to evaluate the technical aspect of communication, specifically focusing on satisfaction with IT tools used during the pandemic for remote and hybrid work. **The research aimed** to assess how these tools impacted communication satisfaction, which, in turn, is believed to contribute to organizational resilience. The assumption, supported by literature (discussed in the introduction), is that effective communication during a crisis lays the foundation for organizational resilience.

The first stage of the research consisted of a mapping review (Lönngren, Van Poeck, 2021) of the relevant literature. The choice of this review method was dictated by the research questions, theoretical assumptions, and the scope of the investigation. The literature surrounding the Communication Satisfaction Questionnaire (CSQ) was analyzed across three main areas:

- Evaluation of the Questionnaire's Quality: This group of studies examined the reliability and validity of the CSQ (e.g., Deconinck et al., 2008; Tkalac Verčič et al., 2007).
- Context-Specific Implementations: These studies focused on how the CSQ has been applied in specific contexts, countries, or sectors. Examples include its use in the Indian context (Verghese, 2017; Tewari, Saraswat, 2017), in Palestine (Alsayed et al., 2012), and in the Turkish postal service (Okay, Okay, 2009). The CSQ has also been used in sector-specific studies, such as in the nursing profession (Wagner et al., 2015).
- Interdependence of Communication Satisfaction and Other Organizational Factors: This field examined the relationship between communication satisfaction and various organizational outcomes. Examples include job satisfaction among intensive care unit nurses (Vermeir et al., 2018), employee engagement (Iyer, Israel, 2012), organizational identification (Nakra, 2006), communication satisfaction in virtual workplaces (Akkirman, Harris, 2005), and the relationship between job satisfaction and job performance (Pincus, 1986).

Additionally, we encountered some critical evaluations of the CSQ itself, pointing out limitations. For instance, some studies were restricted to a single organization (e.g., a private higher education institution in South Africa, Meintjes, Steyn, 2006) or focused on a specific aspect of the communication process, such as communication audit techniques (Zwijze-Koning, de Jong, 2007).

To clarify the scope of extending the questionnaire with the construct we prepared, it is necessary to refer to the essence of mediated communication – IT tools allow for online communication, when the sender and receiver connect through IT tools and communicate simultaneously, and offline, when the sender issues a message in the absence of the receiver's presence, and the receiver responds at another time, comfortable for him. The alternation of formal and informal communication stems from the nature of communication in an organization. These were the reasons behind the use of the 4 questions to explore each of the possibilities.

Data collection and research sample analysis

For the next step of the study, data collection was required using quantitative research methods. A verified and reliable questionnaire was adopted for this purpose, specifically the Communication Satisfaction Questionnaire (CSQ) developed by Downs and Hazen (1977). The data collection process was outsourced to a professional market research agency. The questionnaires were integrated into a single electronic form, and the data were collected via the Computer-Assisted Telephone Interviewing (CATI) method. The respondents were employees based in Poland. A filter question was used to ensure that only individuals who worked online were eligible to participate in the survey. The research was conducted during the pandemic, in the first quarter of 2022, during a time of crisis. The extended CSQ questionnaire was used for the survey. A total of 700 complete responses were collected.

Table 1 outlines the structure of the study group. More than 70% of the respondents were young people born after 1980. Female respondents comprised 49.29% of the sample, while male respondents represented 50.71%. Most of the respondents had extensive professional experience with a single employer. Approximately 52.29% had been employed for more than three years, 27.14% had been with their employer for 1 to 3 years, and 12.57% had worked for the same employer for half a year. Furthermore, 42% of the respondents had more than one year of experience working remotely. At the time of the study, most respondents were already well-versed in remote work, with over 90% working remotely more than one day a week. Notably, 28% of respondents worked remotely five days a week or more, meaning they worked entirely from home.

Table 1.
The structure of the surveyed respondents

Gender	**Work experience for current employer**	**Remote work experience for current employer**	**Days of remote work per week**	**Age group**
Male	Up to 6 months	Up to 6 months	1	1946-1964 (baby boomers)
355 records/ 50,71%	*56 records/ 8%*	*180 records/ 25,71%*	*59 records/ 8,43%*	*36 records/ 5,14%*
Female	6 to 12 month	6 to 12 month	2	1965-1979
345 records/ 49.29%	*88 records/ 12,57%*	*226 records/ 32,29%*	*150 records/ 21,43%*	*161 records/ 23%*
	1 to 3 years	>1 year	3	1980-2000
	190 records/ 27,14%	*294 records/ 42%*	*229 records/ 32,71%*	*496 records/ 70,863%*
	More than 3 years		4	2001-
	366 records/ 52,29%		*66 records/ 9,43%*	*7 records/ 1%*

Cont. table 1.

			5	
			171 records/ 24,43%	
			more than 5	
			25 records/ 3,57%	

Source: own compilation.

3. Findings and analyses

The original (CSQ) instrument used for thus study was divided into eight dimensions. To determine the degree of communication satisfaction, mean value and basic statistics were calculated for each dimension creating eight composite scores showing statistically significant correlation (table 2).

Table 2.
The descriptive statistics and test of normality (Kolmogorov-Smirnov) for original CSQ dimensions

				Kolmogorov-Smirnov with Lilliefors significance corrections		
CSQ Dimension/Variable	**Sum**	**Mean**	**Stand. dev.**	**Statistics**	**df**	**Sig.**
1.Co-Worker Communication (horizontal communication)/**CW**	3524,60	5,04	0,979	0,094	700	<,001
2. Supervisory Communication/**SC**	3494,00	5,00	1,084	0,092	700	<,001
3. Media Quality/**MQ**	3488,60	4,99	0,967	0,079	700	<,001
4. Corporate Information/**CI**	3379,00	4,83	1,032	0,078	700	<,001
5.Organizational Integration/**OI**	3517,60	5,03	1,044	0,098	700	<,001
6.Communication Climate/**CC**	3434,80	4,90	1,057	0,095	700	<,001
7.Personal Feedback/**PF**	3405,20	4,86	1,104	0,087	700	<,001
8.Subordinate Communication/**CS**	3448,60	4,92	0,974	,0066	700	<,001

Source: own compilation.

To examine the relationship of the IT tools on communication satisfaction an additional composite score for IT tools was calculated based on the mean value of four variables that measured satisfaction with formal/informal and online/offline communication. To assess the overall level of communication satisfaction via IT tools, the mean value and basic statistics were calculated for this composite score. The reliability of the composite variables was tested using Cronbach's Alpha, which indicated a high level of internal consistency among the items ($\alpha = 0.834$).

The original and transformed variable (logit transformation) were evaluated using the Kolmogorov-Smirnov test to assess the normality of the distribution. In all cases, the significance level was less than alpha 0.001, leading to the conclusion that the variables deviated from a normal distribution.

In the next step the statistical relationship between the composite IT tools score and the original 8 dimensions of communication satisfaction was examined using Spearman's correlation showing statistically significant correlations for all dimensions (table 3). Therefore, we can conclude that the perception of IT tools used in formal/informal communication has a measurable impact on overall communication satisfaction.

Table 3.
IT tools and communication dimensions of communication relationship – the results of Spearman's correlation

	CW. Mean	SC. Mean	MQ. Mean	CI. Mean	OI. Mean	CC. Mean	PF. Mean	CS. Mean
Correlation Coefficient	0,750	0,668	0,707	0,599	0,651	0,661	0,611	0,685
Sig.	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	0,006

Source: own compilation.

In the next step of the research perceptions of different forms and types of communication (formal/fnformal, synchronous(online)/asynchronous(offline)), was examined due to gain more insight into the relationship between the IT tools and communication satisfaction during remote and hybrid work reflecting tools used to exchange information. The impact of variables such as gender, remote working experience, number of days working online and age group of the respondent on were examined. Mainly non-parametric tests were applied as the data included both nominal and ordinal variables (Likert scale perceptions).

Gender impact

The Mann-Whitney U test showed a statistically significant relationship ($p = 0.02$) between the variable representing the dimension of the IT tool and gender. To further explore these findings, a t-test was performed to identify specific differences in IT tool assessments across 4 types of communication. The results showed that women rated IT tools more favorably in all types of communication during remote or hybrid work. This difference in assessment was particularly notable in online communication. The differences were statistically significant, as the p-values were below the 0.05 threshold for formal offline, formal online, and informal online communication types (table 4).

Table 4.
Gender influence on the evaluation of communication via IT tools

Communication type		Gender	N	Mean	Std. Dev.	Std.Error Mean	Sig.(2-tailed)/df
Formal	Online	Female	345	5,19	1,142	0,061	(0,017)/698
		Male	355	4,95	1,411	0,075	(0,016)/675
	Offline	Female	345	5,30	1,059	0,057	(0,009)/698
		Male	355	5,06	1,298	0,069	(0,009)/677
Informal	Online	Female	345	5,16	1,094	0,059	(0,035)/698
		Male	355	4,96	1,348	0,072	(0,035)/677
	Offline	Female	345	5,18	1,086	0,058	(0,332)/698
		Male	355	5,09	1,409	0,075	(0,330)/663

Source: own compilation.

Remote/hybrid work experience impact

The statistical relationship between the WorkExperience variable (representing remote working experience of the respondent) and the transformed composite variable representing IT tool dimensions of communication satisfaction was examined. No statistically significant difference (p = 0.12) was found after applying the Kruskal-Wallis test, so no further detailed analysis was conducted for this variable.

Number of days working online impact

The statistical relationship between the DaysOnline variable representing (number of days working online) and the transformed composite variable for IT tools dimensions of communication satisfaction was examined. A statistically significant difference (p = 0.003) was found after applying the Kruskal-Wallis test. In particular, pairwise comparisons showed a significant difference between respondents working 3-5 days (p = 0.036) and those working 3-and more than 5 days remotely (p = 0.038), but no significant differences were observed for other comparisons.

The median values for each number of remote workdays were also calculated giving the results from 5 for those working 1 and 3 days remotely, and 5.75 for those working more than 5 days remotely (all results are included in table 5 part a).

The Kruskal-Wallis test was applied to analyze individual variables in more detail, as shown in table 5 part b. A statistically significant difference (p = 0.002) was found for the Formal/Online communication type. Pairwise comparisons revealed a significant difference between respondents working 2–5 days (p = 0.044) and those working 3-6 days remotely (p = 0.018).

For Formal/Offline communication, a statistically significant difference (p = 0.035) was also observed. Pairwise comparisons showed a significant difference only between respondents working 3 and more than 5 days remotely (p = 0.025).

In the case of formal communication, the mean satisfaction ratings were higher for online communication across all workdays.

For informal/online communication, there was no statistically significant difference in satisfaction based on the number of remote workdays (p = 0.319), so these results can only be interpreted within the research group.

However, for informal/offline communication, a statistically significant difference (p = 0.033) was found for satisfaction based on the number of remote workdays, but no statistically significant differences were observed in any pairwise comparisons.

In the case of informal communication, respondents working more than one day remotely rated offline communication slightly better, although these differences were minor when considering the mean values.

Table 5.
Remote work experience influence on the evaluation of communication via IT tools

a

Days Online	N	Mean	Std.Dev.	Median
1	59	5,025	1,052	5,000
2	150	5,078	0,972	5,125
3	229	4,973	0,982	5,000
4	66	5,178	1,159	5,250
5	171	5,250	1,020	5,250
>5	25	5,620	0,866	5,750

b

Communication type	Days Online	N	Mean	Std. Dev.	Median	Communication type	Mean	Std. Dev.
Formal Online	1	59	4,95	1,224	5,00	Formal Offline	5,15	1,172
	2	150	4,93	1,257	5,00		5,16	1,188
	3	229	4,91	1,349	5,00		5,05	1,209
	4	66	5,17	1,421	5,00		5,24	1,096
	5	171	5,33	1,197	5,00		5,25	1,208
	>5	25	5,64	0,952	6,00		5,80	1,080
InFormal Online	1	59	5,03	1,217	5,00	InFormal Offline	4,97	1,313
	2	150	5,05	1,128	5,00		5,17	1,201
	3	229	4,93	1,292	5,00		5,00	1,196
	4	66	5,05	1,440	5,00		5,26	1,512
	5	171	5,20	1,176	5,00		5,22	1,287
	>5	25	5,36	1,036	6,00		5,68	0,988

Source: own compilation.

Age group impact

The statistical relationship between the AgeGroup variable and the transformed composite variable representing communication satisfaction with IT tools was examine. No statistically significant difference ($p = 0.767$) was found after applying the Kruskal-Wallis test, so no further detailed analysis was conducted for this variable.

4. Discussion and limitations

Respondents provided a positive evaluation of IT tools used for communication during remote and hybrid work. The assessments of both formal and informal communication, in both synchronous and asynchronous modes, were above average. Although not all detailed results reached the required level of statistical significance, the findings suggest that employees are generally satisfied with the use of IT tools as instruments and mediums for communication.

Thus, it can be assumed that, in the event of future situations requiring remote work, communication via IT tools is unlikely to pose a high risk to the continuity of the organization's operations.

The pandemic, as a time of crisis, has served as both a cause and catalyst for various events within organizations. It provided a unique research opportunity to study how individuals and organizations respond to sudden, unforeseen conditions that threaten survival, and it also highlighted methods for rebuilding and adapting companies in the face of such challenges.

This period has led to a significant amount of research and publications, including those utilizing the CSQ questionnaire. After conducting the research described in this paper, we performed another targeted mapping review. This second review focused on the period from 2019 to 2024 (chosen due to the typical inertia in the publishing process), and it revealed that many studies were published during this time comparing communication satisfaction with other organizational factors. However, we did not find any studies in which IT tools were the second factor of comparison.

In the context of achieving the aim of this work, the study by Ali Akkirman and Drew Harris (2005) is particularly relevant. Nearly 20 years ago, they stated in their research: "the virtual workplace does not have a categorically negative impact on organizational communication" (Akkirman, Harris, 2005, p. 404). Their study was based on a single organization, with all workers coming from one company, which contrasts with our research that included a broader range of participants.

According to our findings, women rated IT tools more favorably for all types of communication during remote or hybrid work. This difference in assessment was particularly noticeable in the case of online communication. This finding aligns with other studies showing that women are more likely to work from home than men (Astroza et al., 2020) and that women are more inclined to maintain relationships through text messaging (Arakawa et al., 2023).

More than 70% of the respondents in our survey were young people born after 1980. This can be considered a limitation of the study, as the sample predominantly consisted of younger individuals. However, it is important to note that in the event of future crises or threats to organizations, these young employees are likely to be the ones leading efforts to renew and rebuild the organization. They represent the workforce that will remain in organizations over the coming years and, looking more broadly at the labor market, they are a resource that organizations will continue to rely on. Moreover, they carry with them the experiences gained from the recent crisis.

Another limitation of the study relates to the questionnaire itself. In order to be distributed to Polish respondents, the CSQ had to be translated into Polish by the authors of this paper. The reliability of the translation was verified, similar to previous work by Tkalac Verčič et al. (2021).

The tools themselves and their implementation methods were not investigated, they may have an impact on the perception of satisfaction with communication through them (according to the *user experience* concept). There is a possibility that the tools themselves carry the satisfaction of using them. Additionally, since the research was conducted in Poland, we might assume that, as in other European countries, the IT infrastructure in Poland is well-developed

(Michałkiewicz, Mierzejewska, 2020). It is possible that the overall level of digitalization in the country influenced the respondents' positive assessments of communication satisfaction with IT tools. However, our research did not examine the overall level of digital transformation in the country, nor did it investigate the potential interdependence between digital transformation and communication satisfaction with IT tools.

Moreover, referring to the definition of resilience presented here in the text of introductory section, after conducting the research we would venture to say that the new practices are being developed. And further, based on the results of our research, we can assume that good practices with IT communication tools are emerging, and in the future directions of research it will be possible to exploit the detailed types of practices new or adapted routines may be created by employees to meet their own satisfaction needs.

In this study, the constructs were researched, so in the future we can focus on the detailed content of each construct. In addition, good communication practices using IT tools for organizational resilience in detail – which exact tools support organizational resilience to the highest degree – deserve attention in further research.

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