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Table of Contents

Foreword

FOREWORD

The contributions assembled in this volume present a coherent intellectual tapestry that reflects three mutually reinforcing currents now shaping business administration research. First, a systemic re-orientation toward circularity and low-carbon transition dominates the empirical landscape. Studies of renewable-energy deployment, national energy self-sufficiency, circular-economy legislation, and clustering of green industries jointly reveal that sustainability has moved from peripheral aspiration to strategic centrepiece. Importantly, these inquiries converge on the insight that decarbonisation gains materialise only where policy coordination, technological capability, and organisational commitment intertwine; isolated interventions, whether regulatory or technological, seldom suffice.

Running in parallel is an expansive examination of digital transformation, with artificial intelligence emerging as the analytical workhorse and normative touchstone. Investigations of machine-learning–based pricing, AI-enabled diagnostics, cost-management automation, and Industry 5.0 adoption chart both the promise and the fragmentation of current practice. Cross-country segmentation of AI readiness and firm-size heterogeneity in adoption rates expose a pronounced digital divide that threatens to widen productivity gaps. Yet the collective evidence also underscores that human-centric governance—manifested in workplace trust, gender inclusiveness, and capability-building for smaller enterprises—conditions the ultimate returns to advanced analytics.

A third thematic strand links operational sustainability with financial and valuation paradigms. Research on additive manufacturing, procurement-risk information systems, and circular production management demonstrates how data-rich operational tools translate environmental intent into measurable performance, while integrative valuation work extends traditional finance by embedding intangibles, option-like strategic opportunities, and ESG metrics. Across these studies, sophisticated quantitative methods—hierarchical clustering, panel regression, real-options modelling—serve less as ends in themselves than as instruments for illuminating complex, multi-level causality.

Taken together, the papers point to a general pattern: competitive advantage in the contemporary energy-intensive economy now arises from the reciprocal amplification of digital capability, sustainability orientation, and inclusive governance. Data-driven decision frameworks empower firms to identify circular opportunities; circular commitments, in turn, create rich domains for AI deployment; and inclusive organisational cultures maximise learning and diffusion effects. The proceedings thus map a research frontier where innovation and stewardship are no longer viewed as trade-offs but as co-evolving pillars of long-term value creation.

The Impact of Artificial Intelligence Implementation on Business Productivity: A Systematic Literature Review

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Abstract: The rapid development of artificial intelligence (AI) has led to its growing use in business. AI tools offer benefits like cost optimization, competitive advantage, and better decision-making. However, concerns related to ethics, data privacy, trust, and costs still represent significant barriers that hinder companies from embracing AI. This raises questions about the real impact of AI on companies. This study presents a systematic literature review focused on how AI implementation affects businesses across sectors. Relevant literature was identified through searches in Web of Science and Google Scholar, using keywords such as "artificial intelligence influence" and "implementation of AI". A total of 39 studies were selected based on specific criteria. Results show that AI is used in various fields, such as education, marketing, manufacturing, and construction. Its effects were grouped into five key areas: financial and economic performance, human resources, production and logistics, sales and marketing, and innovation. Most studies report positive outcomes, including higher efficiency and improved management. However, some also mention negative impacts like increased employee stress and possible risks to company value. The findings suggest that while AI offers many advantages, companies must carefully weigh its risks and benefits to use it effectively.

Keywords: Artificial intelligence, AI influence, technology adoption.

Introduction

The implementation of artificial intelligence (AI) has brought a revolutionary shift in work processes and continues to be increasingly adopted by many companies. Its integration has become a popular trend, as businesses seek to boost efficiency and competitiveness. AI-powered systems can optimize decision-making, automate routine tasks, analyze large datasets, and forecast trends or costs (Tairov, Stefanova, Aleksandrova & Aleksandrov, 2024). These capabilities help companies increase productivity and adapt to changing markets.

These advantages have led to widespread use of AI tools across sectors such as healthcare, law, finance, manufacturing, and marketing. For instance, in healthcare, AI is used for disease diagnosis and personalized treatment (Katwaroo, Adesh, Lowtan & Umakanthan, 2024), while in the legal field, it supports document analysis and automates contract-related processes (Emejuo, Joseph, Odeyemi & Onumsinachi, 2024). According to the Chief Legal Officer Strategy Survey conducted by Deloitte, two-thirds of companies plan to increase investment in generative AI, recognizing its strong potential to create value for their organizations (Deloitte, 2024).

However, some companies remain hesitant to adopt AI due to doubts about its benefits, high distrust in new technologies, or implementation challenges (Cubric, 2020). Critics also point out potential drawbacks, such as reduced employee influence over work processes, increased risk of data breaches, and ethical or legal challenges arising from the novelty and insufficient regulation of this technology. The aim of this study is to analyze the impact of AI on business processes through a systematic literature review and provide deeper insights into the consequences these innovations may bring.

1. Literature Review

Artificial intelligence can be interpreted as a system's ability to identify, interpret, draw conclusions, and learn from data to achieve predefined organizational and social goals (Mikalef & Gupta, 2021). It encompasses a wide range of advanced analytical methods, applications, and logical approaches that mimic human behavior, decision-making, as well as learning and problem-solving processes (Ludger, 2009), and it is widely applied across various fields. For example, in financial institutions, AI is used for credit scoring and fraud detection (Wamba-Taguimdje et al., 2020); in healthcare, for disease diagnosis; and in commerce, for optimizing sales and marketing processes using chatbots and personalized recommendation systems (Monroy-Osorio, 2024). The development of new AI tools, especially generative AI, has contributed to the increased implementation of this technology in routine business processes, including document processing, data analysis, forecasting, operations automation, and customer interaction.

In business environments, various types of AI tools are used, such as data analytics and machine learning tools; generative models (e.g., GPT, Gemini) (Raj, Singh, Kumar & Verma, 2023); voice assistants and speech recognition systems (Nasirian, Ahmadian & Lee, 2017); and natural language processing tools such as chatbots (Chen & LeFlorence, 2021).

Researchers actively study the application of AI in business, its benefits (Enholm, Papagiannidis, Mikalef & Krogstie, 2022), and the challenges associated with its implementation (Fosso Wamba et al., 2024). The main benefits businesses gain from AI include the automation of routine processes, increased productivity, and reduced time and financial costs. Using AI to analyze large datasets enables companies to identify trends, improve financial performance, and increase customer satisfaction through personalized marketing and automated interactions. Additionally, AI supports strategic decision-making in uncertain conditions and helps adapt business processes, minimizing risks related to unstable environments.

At the same time, several studies highlight the negative aspects of AI adoption. Key concerns relate to ethical issues such as bias in algorithms, data privacy concerns, and lack of process transparency (Fosso Wamba et al., 2024). A major risk factor is data quality: since AI systems rely on processing large volumes of information, poor or biased data can lead to inaccurate predictions and inefficient management decisions (May, Sagodi, Dremel, & van Giffen, 2020). Moreover, excessive reliance on AI may reduce employees' critical thinking and limit human oversight of processes.

The social impacts of AI adoption also raise concerns. Some studies indicate that changes in work processes due to automation may increase tension among employees, trigger conflicts, and foster distrust toward technologies. In the economic context, AI does not always deliver the expected financial benefits. The concept of "efficient inefficiency" suggests that implementing AI in less productive processes may not only fail to improve a company's efficiency but may even cause losses (Mills & Spencer, 2025). Some studies also suggest a negative impact of AI investments on a company's market value, particularly in non-manufacturing enterprises or organizations with insufficient IT resources and low credit ratings (Lui, Lee & Ngai, 2021).

Therefore, given the substantial resources required for implementing AI in business processes, company management should carefully weigh the potential benefits and risks. This research aims to provide a comprehensive analysis of the consequences of AI implementation in companies, considering both the positive and negative aspects of this technology.

2. Methodology

The main goal of our research is to analyze the available literature in order to determine the impact of artificial intelligence tool implementation on businesses. To achieve this goal, we conducted a systematic literature review using a structured approach. After defining the research objectives, we established criteria for evaluating the quality of the scientific papers included in the analysis.

Firstly, we focused only on studies published since 2018, as AI technologies are rapidly evolving, and it is essential to concentrate on the most recent advancements. We also decided to include only empirical research, excluding general literature reviews.

The second step involved extensive searches in academic databases, including Web of Science and Google Scholar. Keywords and their combinations were selected to cover a wide range of areas in which AI is applied. These included: "AI adoption", "Artificial Intelligence use", "ChatGPT", "implementation of AI", "Business benefits", "business value proposition", "business gains". The final search query was formulated as follows:

TS=((AI OR Artificial Intelligence OR ChatGPT) AND (use OR adoption OR implementation OR integration) AND (business benefits OR influence OR business value proposition OR business gains)).

The search, conducted in February 2025, identified 17,110 articles, of which 14,409 were published since 2018. We excluded 7,306 articles due to unavailability. Furthermore, we excluded 136 studies that were not written in English or Slovak, to avoid inaccuracies in translation. After removing irrelevant research (e.g., meta-analyses, literature reviews, or studies that did not analyze the impact of AI on businesses), we were left with 394 studies for further analysis.

The next step was a detailed analysis of the abstracts of the selected studies. After excluding irrelevant or low-quality research, we obtained a final sample of 39 studies that met the established criteria.

In the final phase, we analyzed each of these studies in terms of identifying research gaps, objectives, methodology, the industry in which the research was conducted, and the main findings. To summarize the results, we identified the key business areas in which artificial intelligence has a significant impact and categorized the analyzed studies according to this classification.

3. Results

Based on the results obtained from database searches, we analyzed the abstracts of 394 articles and found that the number of studies devoted to this topic has been increasing annually. The largest surge occurred in 2024, which may be linked to the growing trend of implementing artificial intelligence in business processes. This trend is primarily driven by the development of generative AI (ChatGPT, Gemini, DeepSeek, etc.), which has become more widely accessible. Figure 1 presents the distribution of the analyzed studies by year of publication.

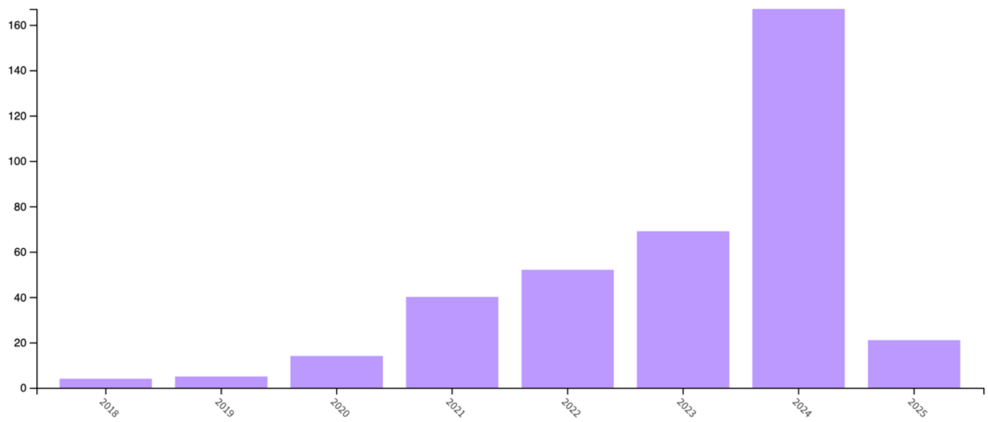

Figure 1. Number of publications on the impact of AI by year

Source: Web of Science, February 2025

A total of 39 studies were selected for further analysis. with varying levels of economic development and different economic systems, specifically: Turkey (Caner, 2024), USA (Mikalef & Gupta, 2021), Germany (Szedlak et al., 2021), Indonesia (Hargyatni, Purnama & Aninditiyah, 2024), China (Chen, Esperança & Wang, 2022), Malaysia (Xin, Wider & Ling, 2022), Jordan (Almustafa, Assaf & Allahham, 2023), India (Chaudhuri et al., 2023; Sahay & Kaur, 2021), South Korea (Mollah et al., 2024), Poland (Orzoł & Szopik-Depczyńska, 2023), Vietnam (Dey et al., 2024), Spain (Gómez-Bengoechea & Jung, 2024), Bulgaria (Kirova & Boneva, 2024), and Slovenia (Rožman, Oreški & Tominc, 2023). In addition, the study by Kochkina, Andriushchenko & Gatto (2024) describes a case of artificial intelligence implementation in a Ukrainian-Canadian company. In the remaining studies, the specific country of research was not stated.

The analyzed studies focus on various sectors, particularly on technology companies (Mikalef & Gupta, 2021), e-commerce (Chen et al., 2022), manufacturing (Dey et al., 2024), the financial sector (Gill et al., 2023), energy (Szczepaniuk & Szczepaniuk, 2022), telecommunications (Sahay & Kaur, 2021), service sector (Orzoł & Szopik-Depczyńska, 2023), and other industries. This indicates that artificial intelligence is being actively implemented across a variety of companies and that its integration truly has a global impact on the economy.

Regarding the impact on individual companies implementing AI-based tools, we found that the effects are quite diverse. To better understand the results, we grouped them into the following categories:

3.1. Financial and Economic Indicators

Most of the research focuses on the impact of artificial intelligence on companies' financial indicators, which often represent a key factor in deciding on further investments in AI tools. The majority of authors point to a positive impact, which can be attributed to several factors. Primarily, innovative technologies, including artificial intelligence, contribute to increased profitability through improved operational processes (Al-Surmi, Bashiri & Koliousis, 2022), automation (Artene, Domil & Ivascu, 2024), enhanced productivity (Babina et al., 2024), and the identification of inefficient processes, leading to cost reduction (Olan et al., 2022).

In addition, the use of AI supports data-driven decision-making processes (Al-Surmi, Bashiri & Koliousis, 2022) and improves financial risk management (Drydakis, 2022). In the analyzed studies, changes in specific financial indicators due to AI implementation are most often evaluated by comparing companies that implemented AI with those that did not. This approach was used in a study by Huang and Lin (2024), who analyzed companies based on indicators such as return on assets (ROA), return on equity (ROE), profit margin, and asset turnover. The results of this study suggest potential changes in financial indicators as a result of AI implementation.

Nevertheless, ineffective integration of AI tools may lead to increased costs without a corresponding increase in profit and even negatively impact company productivity (Kopka & Fornahl, 2024). Research also shows that AI-driven growth occurs primarily among large enterprises and is associated with higher market concentration (Babina et al., 2024). However, several studies confirm that small and medium-sized enterprises can also successfully implement artificial intelligence (Drydakis, 2022).

3.2. Human Resource Management

The use of AI tools is increasingly being implemented in human resource management, as it supports automation and enhances the efficiency of tasks such as employee recruitment, performance evaluation, career management, job design, workforce planning, job position assessment, and employee turnover prediction (Mollah et al., 2024). The application of AI in recruitment processes and talent acquisition can positively influence indicators such as Time to Fill and Cost per Hire (Pan et al., 2023). Furthermore, delegating certain tasks to AI tools allows employees to focus on more complex tasks that require intuitive thinking (Caner, 2024).

AI solutions can also positively impact employee productivity (Kassa & Worku, 2025), and their implementation in HR processes facilitates real-time data collection on individual performance thanks to digitalization (Xin, Wider & Ling, 2022). Reducing workload may contribute to lowering perceived employee stress, which in turn positively affects employee engagement and overall company productivity (Rožman, Oreški & Tominc, 2023). On the other hand, introducing new technologies into work processes creates a need for continuous employee education, as they must acquire the digital skills required to work with AI (Jaiswal, Arun & Varma, 2023).

However, some studies suggest that under certain conditions, employee productivity may even decline (Babina et al., 2024; Kopka & Fornahl, 2024). Organizations may also face the issue of excessive reliance on AI, which can weaken employees' critical thinking and reduce their decision-making capabilities, potentially leading to negative consequences (Mills & Spencer, 2025). Low trust in AI can also trigger internal resistance to further innovation (Czarnitzki, Fernández & Rammer, 2023). Some research indicates that the introduction of AI may, in specific cases, negatively impact employment levels, particularly in certain market segments or smaller firms (Babina et al., 2024).

Although for companies this often means cost optimization, excessive use of AI may undermine employees' sense of job security, as they may fear job loss due to automation. Therefore, it is crucial that the implementation of AI tools into work processes is carried out with transparent communication with employees, so they feel included in these changes and do not develop resistance to innovation.

3.3. Production Processes and Logistics

The use of artificial intelligence also has a significant impact on production and logistics processes in companies and represents a key tool for their automation (Zebec & Indihar Štemberger, 2024). The integration of Big Data with AI can identify weaknesses in the supply chain, increase process efficiency, extend equipment life cycles, and reduce industrial waste (Chen et al., 2024), as well as lower logistics costs and more accurately forecast demand (Drydakis, 2022).

As Gómez-Bengoechea (2024) points out, AI can be used to automate communication, including text- and voice-based AI solutions or speech generation. These technologies are applied in logistics to improve customer communication, automate order processing, and optimize delivery routes.

The implementation of AI into work processes enables more efficient use of company resources, which positively affects not only production and delivery times but also overall costs.

3.4. Sales and Marketing

The area of sales and marketing has undergone significant transformation due to artificial intelligence, which is evident in many aspects. AI tools based on data analysis can identify important insights into customer behavior and uncover key market trends (Mikalef et al., 2023), thereby contributing to increased sales volume. AI is also used to optimize marketing campaigns, personalize offers, and improve the return on investment in marketing (Al-Surmi, Bashiri & Koliousis, 2022), as well as to automate marketing processes to enhance their efficiency. Additionally, AI systems assist marketing companies with creative tasks (Vakratsas & Wang, 2020) and optimize advertising campaigns.

Artificial intelligence also contributes to improving customer service. For example, companies use Robotic Process Automation (RPA) to collect customer feedback and suggestions, providing valuable information for developing business strategies focused on meeting demand (Kumar & Balaramachandran, 2018). AI is also integrated into Customer Relationship Management (CRM) systems (Chatterjee et al., 2021), enabling better sales management and more personalized communication with customers.

Overall, there is a positive correlation between AI implementation and growth in market share and sales profitability (Babina, 2024). Research by Zhan et al. (2024) further showed that companies announcing AI adoption in B2B marketing experienced a positive impact on their stock value.

3.5. Research, Development and Innovation

The implementation of artificial intelligence can support the development of an innovation culture within a company and accelerate research and development processes (Hossain, 2024). Furthermore, AI systems help identify new market opportunities. Research by Mikalef and Gupta (2021) showing that the advanced potential of artificial intelligence can positively influence an organization's ability to generate new and useful ideas, which is a key element of innovation. AI thus represents a significant factor that stimulates and transforms companies' innovation activities. It impacts the development and creation of new products, processes, and ideas, supports research, enhances organizational creativity, and contributes to the growth of inventive activity.

4. Discussion

Based on the analyzed studies, it can be concluded that the implementation of artificial intelligence tools has a significant impact on company productivity. Although some research points to possible negative consequences, such as increased costs without a corresponding increase in profit or decreased productivity of certain employees, most studies confirm the positive effect of AI. Key benefits include increased productivity, optimization of business processes, reduction of costs and production time, improved customer interaction, and increased sales. These improvements are subsequently reflected in financial indicators of companies, such as return on assets (ROA), return on equity (ROE), profit margin, asset turnover, and stock value. Nevertheless, there are mentions of potential negative impacts, which highlights the importance of a thorough risk analysis by management before implementing AI tools into work processes.

The analyzed studies focused on companies from various countries and sectors, including banking and financial services, technology companies, service sector, industry, manufacturing, energy, and marketing. This suggests that artificial intelligence tools are being successfully implemented across different industries and economies.

However, our research findings have certain limitations. The selection of literature may have influenced the diversity of results, as our review was based exclusively on available scientific sources that might not have covered all aspects of AI's impact on companies. Additionally, the dynamic development of artificial intelligence must be taken into account, as the relevance of our findings may decrease over time.

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Production Management and Sustainability

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Abstract: Sustainability in the production management involves introduce and improves the economic, social, and environmental factors into businesses operations. Socially, it includes community empowerment as well as fair employment. From an environmental perspective, the main advantages will include pollution reduction, minimizing waste and resources conservation. In the economic sense sustainability means that corporations need to have continuous profit margins as they cater to the needs of the present and future generations.

Keywords: production management; sustainability; environmental impact; circular economy

Introduction

The impact of productions efficiency does not finish with only one company, it spreads across the whole industries and economy systems. Through optimization of production process, there will be a reduction in costs, better quality, shortage of time for production, and enhanced customer satisfaction. As a result, it serves as a stimulus for innovation, competitiveness and ultimately, business expansion whereas these concepts are in the hands of sustainable principles.

Nowadays, environmentally friendly consideration turns to be an omnipresent factor of the global community, inspiring new behavioral trends and change of the world. In consequence, an awareness of mindfulness expands covering all spheres of life, such as production management, where sustainability has recently become the top priority. This research will investigate the transformation of production management by generating lens of sustainability which will also be used to highlight trends in sustainable production management practices.

Efficiency in production management is basically one of the factors that ensure productivity across diverse sectors. This entails strategic planning, coordination, and process administration in order to meet the needs in the production of quality products for customers. Gradually, production management methodologies have changed in accordance with the increasingly dynamic environment and other factors, leading from basic to complex methods.

1. Literature review

Organizations' desire to incorporate sustainability and corporate social responsibility into their operations management procedures has significantly increased in the last several years. Growing awareness of environmental issues, climate change, and broader social demands involving the welfare of communities and workers have all contributed to this transformation. The notion of Sustainable Operations Management, which is the pursuit of social, economic, and environmental goals – the triple bottom line – within an organization's operations, expanding its operational connections to include the supply chain and communities, is fundamental to this shift.

The idea of sustainable manufacturing is to place a higher value on long-term effects and advantages than on immediate gains. Businesses can prosper by making investments in resource-efficient technology and procedures, well-built, safer products, and knowledgeable, capable staff. Furthermore, the advantages of sustainable production become even more clear in light of the public's increased concern over climate change and the efforts being made to create green cities and towns. Adhering to sustainable practices not only demonstrates an organization's commitment to social and environmental responsibility, but it also sets it up for success in a time when environmentally conscious and ethical customer behavior are key factors.

Product design, eco-design, social and environmental standards, process optimization, lean operations, procurement, supply chain management, logistics, performance evaluation, and risk management are just a few of the topics covered by sustainable production management. Organizations can reap the benefits of increased efficiency, decreased environmental impact, and positive social effect while also helping to create a more resilient and sustainable future by comprehending and putting sustainable ideas into practice in these areas. (Umas, 2024)

2. Methodology

The main goal of the paper is to clarify the production management, sustainability. In the introductory part of the paper, we described the basic definitions of terms related to the issue. The results of the work and the discussion resulted in statements regarding sustainable production management. To process the information and knowledge in the paper, we used the methods of analysis, synthesis, induction and deduction.

3. Results

3.1. Explanation of the social, environmental and economic aspects of sustainability

As the world grows more aware of social, environmental, and economic challenges and shareholder concerns, businesses are making a more significant effort to behave as better corporate citizens. Entrepreneurs understand that socially and environmentally sustainable growth needs long-term economic expansion. A competitive advantage can result from striking a balance between social responsibility, economic advancement, and environmental protection—a concept known as the "triple bottom line." Businesses can more thoroughly evaluate their economic, societal, and ecological effects by examining their processes and goods. They can also determine how enhancing sustainability impacts and boosting long-term financial success interact. (Epstein, at. all, 2014)

Environmental sustainability is about protecting the environment by using the proper practices and regulations to meet the needs without sacrificing the availability of resources for future generations. (Moldan, B. at all, 2012) Weinstein defines "needs" as having access to clean water, wholesome food, and secure housing, all of which billions of people still lack. A worldwide nonprofit organization called Water estimates that 771 million people, or around one in ten, lack access to clean water. It is evident that environmental sustainability necessitates a certain degree of selflessness to make sure that future generations are taken into account. (Patterson, 2024)

As our population grows, economies grow, and resource demands rise, natural resource management becomes more and more important. A global plan that prioritizes management, resource protection, and demand reduction is required to address this. In order to preserve biodiversity and ecosystems and to control the exploitation of resources, conservation is essential. It is important to use less and use resources like water, energy, and materials more wisely. Sustainable development also ensures ethical forestry, energy, and agricultural methods. (Zakari, 2021)

Deforestation and excessive use are examples of unsustainable practices that contribute to resource shortages and damage to the environment. The degradation of the soil, water scarcity, and loss of biodiversity are caused by this. There are health concerns associated with air, water, and land pollution. Reducing dependency on resources and creating a sustainable lifestyle are essential to addressing this. This involves changing one's way of living to choose more sustainably produced foods and energy sources and to reduce waste. Legislation that will reduce pollution and save habitats must also be implemented by corporations and governments. (Wassie, 2020; Grančičová and Hrušovská, 2022).

It is essential to implement additional methods such as garbage reduction, increased recycling, and energy conservation. We reduce waste to reduce the burden on energy and resources. Recycling lowers manufacturing energy use and reduces the requirement for fresh materials. Energy conservation lowers overall energy consumption and greenhouse gas emissions. Examples of conservation include turning off lights and adopting devices that are energy-efficient. (Manisalidis, at all, 2020)

In social sustainability, we aim for a good standard of living instead of just getting by on our most basic needs. Intergenerational equality is a crucial component, which means we should manage natural resources responsibly now so that future generations can benefit from them as well.

We must better the lives of those who don't have access to enough food, clean water, or shelter in order to accomplish this. A clean environment, health, cultural demands, and growth in populations are further important factors. These elements have a direct impact on people's wellbeing and shouldn't be ignored in favor of quick financial advantages.(Mohamed, at all, 2021)

The quality of a business's interactions and connections with its stakeholders is crucial. Businesses impact the lives of employees, value chain participants, clients, and local communities directly or indirectly. For this reason, it's critical to manage impacts early on. Their social sustainability initiatives primarily determine businesses' social license to function. Business operations and growth can also be hampered by a lack of social development, which includes poverty, inequality, and a lax rule of law.

Achieving social sustainability can also open new markets, draw in and keep business partners, or inspire creative ideas for new product or service offerings. Employee involvement and internal morale may increase as productivity, risk management, and company-community conflict improve. While governments are primarily responsible for safeguarding, upholding, fulfilling, and gradually realizing human rights, companies can and need to play a role. At the very least, companies should create precautions to prevent human rights violations and repair any negative effects on human rights that may arise from their operations. Businesses can take extra measures in addition to protecting rights, not in place of them: make additional contributions to better the lives of those they impact, such as by establishing inclusive value chains, well-paying jobs, and products and services that assist in meeting fundamental requirements. Invest wisely in society and advocate for laws that uphold social sustainability. Collaborate with other companies, combining abilities to have a more significant, better effect. (UN Global Compact, 2025)

Economic sustainability aims to conduct economic activity to maintain and advance long-term economic well-being. Its practical goal is to achieve a balance between financial stability, social equality, resource efficiency, and economic growth.

Standards for economic sustainability are rules that hold apply to all systems. These requirements highlight the value of consistency and diversity in economic institutions, practices, and technologies, going beyond conventional metrics of economic performance. In order to sustain coexistence without controlling other systems, they emphasize the necessity of balanced trade of products and services with other economies, stressing both monetary and physical exchanges. These standards also highlight the opportunity for innovation in the areas of technology, institutions, the economy, and society. Enough contributions to overall quality of life, unity in society, environmental sustainability, and institutional sustainability are necessary to guarantee the economy's long-term survival. (Spangenberg, 2005)

3.3. Evolution of sustainable production management

The idea of sustainable production management has become dynamic and transformational, transforming over time in response to shifting social, economic, and environmental conditions. This chapter examines the development of sustainable production management from the beginning to the present, characterized by international efforts, innovations in technology, and shifting expectations among stakeholders.

The industrial output and supply chains have been strained by increasing demand for products and their consumption, which has had a damaging impact on society and the environment. (Rajeev, at all, 2017) Governments, corporations, and society as a whole are very interested in environmental sustainability. Numerous institutions have implemented a wide range of sustainability initiatives and methods to reduce their usage of natural resources and minimize their influence on the ecosystem. Organizations have begun to engage heavily in the measurement of sustainability-related factors as interest in sustainability "has moved from ideology to reality. (Mura at all, 2018)"

According to earlier manufacturing research, rapid industrialization with the ability for customization results in high investment rates, but it also leads to high resource consumption and contamination processes that worsen pollution and energy shortages. As a result, a number of manufacturing strategies that address the scarcity of natural resources and technology driven by the dynamics of economic systems as well as sustainable manufacturing practices have been put forth. Inspired by discussions about the lack of abundant natural resources, pollution control programs were first introduced in the 1970s. However, 21st-century strategies now view industrial ecology as part of a "system of systems" that connects multiple closed-loop production systems with a harmonious and interconnected circular flow of resources. (Janahi, at all, 2021)

Plan evolves as a result of studies showing that previous expositions emphasize sustainability as a socio-technical characteristic of a development plan, focusing more on a "desirable" society than a "feasible" one. Recent studies, however, emphasize sustainability as a dynamic and changing notion that requires adjustments to variables and tactics because of socio-technological shifts in society and industry.

Manufacturing plans are typically based on assessments of market potentials and associated risks. This emphasis is due to the fact that manufacturing companies are a part of wider networks and national innovation systems that need taking the environment into account while producing goods and the broader economies of countries and regions. As a result, for these networks and systems to be sustainable, entities (such as governments, customers, researchers, etc.) must take initiative, become involved, and reinvent their roles. Organizationally, these shifts necessitate proactive management techniques and business plans that encourage eco-innovation for producers, including the social manufacturing idea put forth by that encourages varying degrees of user involvement in the manufacturing process. Establishing institutional standards and concepts that ensure eco-innovation for manufacturing enterprises is prioritized is beneficial for sustainability transitions. (Janahi, at all, 2021)

4. Conclusion

One of the key principles of Sustainable Operations Management is Sustainable Production, which is the process of producing goods and services through energy- and resource-efficient systems and processes that are also economically viable, safe and healthy for consumers, communities, and workers, and socially and creatively fulfilling for all workers. Communities, businesses, workers, and the environment all stand to gain from the comprehensive integration of these ideas. In addition to providing long-term benefits, this frequently produces immediate wins as well, promoting successful and profitable businesses. (Walker, 2014)

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Spillover effects of cultural and creative industries

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Abstract: Cultural and creative industries (CCIs) are among the dynamically developing sectors of the modern economy, which combine culture, art and creativity with entrepreneurship and innovation. This article presents the basic definitions, characteristics, specifics of CCI, while pointing out its economic, social and symbolic significance. It focuses mainly on the side effects of CCIs, such as the wider impacts of knowledge, products, services and established cooperation networks on regions, the economy and society. The content of the article is based on relevant professional literature, reflecting the current challenges and opportunities of this sector in the context of digital transformation.

Keywords: cultural and creative industries; creativity; culture; specifics; spillover effects

Introduction

The Cultural and creative industries (CCIs) are currently one of the most dynamic sectors of the global economy, growing significantly in the last two decades and becoming one of the key sectors of post-industrial society. This sector represents the interconnection of art, culture, technology and business. Its importance goes beyond a purely economic aspect, as it includes the production and distribution of goods and services that bear a cultural identity and contribute to the strengthening of cultural diversity.

1. Literature Review

According to UNESCO data, global trade in cultural goods and services has exceeded $620 billion and doubled in the last decade, proving that culture is a powerful force for both economic and social development. (Europa Regina, 2023). Despite the importance of cultural and creative industries, there is still considerable inconsistency in its definitions. Different approaches are used to define it, leading to different estimates of its size, impact and contribution to the economy. This makes it difficult to develop effective policies and targeted measures to support the sector.

1.1 Definitions of cultural and creative industries

There are several definitions of cultural and creative industries, which vary depending on the institution and historical context. UNESCO defines cultural and creative industries as "industries that combine the creation, production and distribution of intangible and cultural content. This content is generally protected by copyright and may take the form of a product or service" (DP, 2025) In addition to the overall cultural and artistic production, it also includes architecture and advertising. In the 2009 Framework for Cultural Statistics, UNESCO further specifies that these are "sectors of organized activity whose main purpose is the production or reproduction, promotion, distribution and/or commercialization of goods, services and activities of a cultural, artistic or heritage nature". This definition emphasizes not only the products of human creativity produced industrially, but also the entire productive chain and the specific functions of the sector. (Europa Regina, 2023)

In the British context, the creative industries were defined in 2001 as "industries that have their origins in individual creativity, skill and talent and that have the potential to generate jobs and prosperity through the creation and use of spiritual property." (DP, 2025)

Cultural and creative sectors include all sectors whose activities are based on cultural values or artistic and other individual or collective creative expressions, as defined in the legal basis of the Creative Europe Programme. 'Cultural and creative sectors' means all sectors whose activities are based on cultural values or artistic and other individual or collective creative expressions. These activities may include the development, creation, production, dissemination and protection of goods and services that constitute cultural, artistic or other creative expressions, as well as related activities such as training or management. They will have the potential to bring innovation and jobs, especially in relation to intellectual property. These sectors include architecture, archives, libraries and museums, arts and crafts, audiovisual (including film, television, video games and multimedia), tangible and intangible cultural heritage, design (including fashion design), festivals, music, literature, performing arts, books and publishing, radio and visual arts. (EP, 2013)

The concept of cultural and creative industries is currently of high social and political importance. It includes 'cultural and creative enterprises which are predominantly commercially oriented and are involved in the creation, production, distribution and/or media dissemination of cultural/creative goods and services'. The definition shows that it is a cross-cutting industry that includes many sub-markets. These range from the creation of cultural or creative goods to services, and show that the cultural and creative industries are very heterogeneous. (Weißmann, S., & Liersch, A. 2021)

The term creative industry refers to activities that create economic value on the basis of individual creative input or artistic talent based on the valorization of intellectual property, which can include areas of creative activity such as architecture, design, film, music, visual and theatrical arts, as well as the creation of computer games or advertising. However, this issue affects not only the field of culture and creativity, but also many sectors of the economy and plays a key role in the process of digitalisation and globalisation. (MK SR, 2020)

The core of any cultural and creative economic activity is the creative act of artistic, literary, cultural, musical, architectural or creative content, works, products, productions or services. All creative endeavors are included here, regardless of whether they are unique analogue works, live performances, serial or digital productions or services. Likewise, creative acts can be protected by copyright in the broadest sense (patent, copyright, trademark, design rights). However, they can also be without references to copyright (for example, in the case of performers)' The concept of the 'creative act' is a unifying element of all cultural and creative sectors, as it is an extremely complex, highly subjective concept – similar to the concepts of 'culture' and 'creativity'. (Mundelius, M. 2018)

1.2 Typology of cultural products and services

The outputs of the cultural and creative industries represent a wide range of products and services. Based on Eurostat data (2025), several main categories of economic activities can be identified, which together form a cultural aggregate:

- Printing and reproduction of recorded media; production of musical instruments and jewelry;
- Retail sale of cultural goods in specialized stores;
- Publishing activities;
- Film and television, sound recordings and music publishing; Rental of videocassettes and discs;
- Programming and broadcasting; Activities of intelligence agencies;
- Architectural activities;
- Specialized design activities;
- Photographic activities;
- Translation and interpreting activities;
- Cultural education;
- Creative, artistic and fun activities;
- Libraries, archives, museums and other cultural activities.

1.3 Specifics of the cultural and creative industries

The cultural and creative industries (CCI) are characterized by several specificities that distinguish them from traditional economic sectors. These specifics have an impact on the way the market works, business, and the creation of policies aimed at supporting this sector.

One of the most important economic specifics of the cultural sector is the so-called Baumol effect, also known as Baumol's disease of costs. This phenomenon, first described by William J. Baumol and William G. Bowen in the 1960s, refers to the tendency of wage growth in low-productivity industries in response to wage growth in high-productivity industries. (Wikipedia, 2025). Wages are also rising in those sectors that show minimal to zero productivity growth. This leads to an increase in the price per unit of production in these sectors. Typically, it concerns services such as healthcare, education, or culture. (INESS, 2023)

This effect explains several important economic trends:

- The share of total employment in sectors with high productivity growth is declining, while it is growing in sectors with low productivity;
- Economic growth is slowing due to a smaller share of high-growth sectors in the overall economy;
- Government spending is disproportionately affected by the Baumol effect, due to its focus on services such as healthcare, education, and law enforcement;
- Rising costs in labour-intensive services are not necessarily the result of inefficiencies.

Given that many cultural and creative industries are labour-intensive and have limited potential for increasing labour productivity (e.g. live performances), the Baumol effect has a significant impact on their economy and sustainability.

At the same time, CCI enterprises, in particular SMEs, have specific characteristics that distinguish them from "normal" business. They often operate in specific market conditions, produce goods that are inherently 'cultural', work with people who are often more focused on the entrepreneurial dimension of the CCIs on content than on the commercial side, and usually create very small enterprises (micro-SMEs) that exist on the basis of permanent networks. (HKU, 2010)

One of the most significant characteristics of CCI is its structure - it is dominated by small and medium-sized enterprises. According to Eurostat statistics from 2022, there were 2.03 million cultural enterprises in the EU, which represented 6.3% of all enterprises within the business economy7. Most of them belong to the category of small and medium-sized enterprises, which generate a significant part of the added value in this sector. The distribution of these enterprises among EU Member States is uneven. The share of cultural enterprises was particularly high in the Netherlands (11.0%) and Sweden (10.8%), while in Bulgaria and Slovakia cultural enterprises represented only 3.1% of the business economy (Eurostat).

Another important characteristic is the sectoral structure. More than a quarter of cultural enterprises in the EU are engaged in creative, artistic and entertainment activities (27.4%). Publishing (14.9%) and architectural board (14.6%) account for the largest share of the total value added generated by the EU's cultural sector.

The cultural and creative industries (CCI) are characterized by several specificities that distinguish them from traditional economic sectors. These specifics have an impact on the way the market works, business, and the creation of policies aimed at supporting this sector.

The distinctive features of CCI are:

- **Creativity as the main factor of production -** in contrast to production industries, where the main role is played by physical labor or capital, in CCI the dominant production input is human creativity. The outputs are unrepeatable and unique**.** Every work, product or service is the result of a creative process, often without an exact duplicate. This factor leads to a high degree of individualization of work, low predictability of results and the need for continuous innovation. As a result, a **project type of work organization is more common in** CCIs, where people come together for specific creative projects.
- **Symbolic value –** products often carry meanings that go beyond their functional value.
- **Uncertainty of revenues** - creative products have an unpredictable market value, which emphasizes managerial skills and flexibility.
- **Non-formal learning and interdisciplinary collaboration** – creative professionals often acquire **their** skills outside the formal school system – through courses, mentoring or community practice. In many cases, successful projects are the result **of interdisciplinary collaboration** between artists, designers, technologists and entrepreneurs. This type of education and cooperation places new demands on educational institutions and labour market policy.
- **Non-standard forms of employment - unstable forms of work** - in CCI, contract employment or micro-entrepreneurship is common. The dominance of micro-enterprises is accompanied by a large share of sole traders. According to the European Creative Business Network (2018), up to 75% of

workers in this sector have an unstable income. This fact reduces the social security of workers and makes it difficult for them to access mortgages, pension systems or sickness insurance.

- **Mobile, flexible, and increasingly virtual working methods** – open communities need not only virtual platforms for personal connections, but also physical workspaces. Expansion to the creative environment, in addition to digital networks, enables real cross-sectoral and project-based **cooperation** in various areas of knowledge. Due to the heterogeneous composition of creative professionals in joint projects, valuable breeding ground for ideas is created. A high degree of mobility and flexibility, as well as a virtual infrastructure based on real needs, are essential for independent work in the creative industries.
- **Digitalization - ICT is an indispensable cross-cutting technology -** in recent years, there has been a massive digitization of CCIs. It represents one of the most significant factors influencing this industry. Online distribution platforms have fundamentally changed the way creative works are produced, distributed, and monetized. Information and communication technologies are a cross-cutting technology that is now used across industries and is integrated into almost every value creation process. ICT infrastructure serves as a (virtual) network platform in many sectors, representing both a means of production and a distribution channel. Digitalisation has a significant impact on all stages of the value chain in the cultural industries – from creation to distribution and consumption. Digital technologies bring new opportunities for the creation, dissemination and consumption of cultural content, but also bring new challenges related to copyright protection, pricing and sustainable business models. Creative workers benefit mainly from technological advances in ICT through their independent working methods. In addition, digital technologies have spurred the emergence of new business models in many sectors. They also offer alternative **solutions** in the process of opening up networks and creating value as complementary tools to unlock innovation potential. More and more external actors (customers, business partners, competitors, suppliers, etc.) are integrated into value creation. (Deutsche Bank Research, 2011)

2. Methodology

The aim of the article is to define the term cultural and creative industry, to state the typology and define the specifics of this industry on the basis of the study of domestic and foreign professional literature on the subject using general scientific methods - analysis, synthesis, induction and deduction. In this paper, we will focus mainly on identifying, characterizing and analyzing the content of its side effects that affect the businesses themselves, the community, but also the wider economy.

3. Results

The cultural and creative industries generate a variety of side effects. Based on the study of professional literature, we have identified the following effects:

A. According to the Policy and Evidence Centre (2020), the following types of basic side effects of the cultural and creative industries are distinguished:

- **sectoral effects** - where expenditure in the supply chain is triggered by the activity of creative industries;
- **knowledge effects** - where new ideas spread to other sectors;
- **supply-side effects** – where the facility or location attracts skilled workers and visitors;
- **innovation effects** - which include the creation of new knowledge in the field of product and service innovation.

B. Söndermann presents the following internationally recognized typology of side effects of the cultural and creative industries:

- **Knowledge transfer** refers to new ideas, innovations and processes created by arts organisations, artists and creative societies operating in the economic and social spheres, without their authors being remunerated in any way.

- **Product transfer** refers to the vertical value chain and horizontal cross-sectoral benefits to the economy and society in terms of productivity and innovation resulting from the impact of dynamic creative activity by businesses, artists, arts organisations or arts events.
- **Network effects** refer to the effects and outcomes on the economy and society generated by the presence of a high density of arts or creative industries in a particular place (such as a cluster or cultural districts). The associated effects result from clustering (such as the spread of tacit knowledge) and give rise to agglomerations, the advantages of which are, for example, high economic growth, regional attractiveness and specific cultural identity. However, there are also frequent negative consequences – e.g. exclusive gentrification.

These segments are further subdivided and the impact of the following effects within each effect category is specified:

Knowledge transfer includes:

- Stimulating creativity and fostering the potential of stakeholders
- Increasing visibility, tolerance and exchange between interest groups
- Changing attitudes through cultural participation and openness to artistic creation
- Increasing the labour market/employment and skills development in society
- Increased cross-border and cross-sectoral cooperation
- Experimenting with new organizational and management structures
- Facilitating knowledge sharing and culture-based innovation

The transfer of the product is triggered by:

- Improving corporate culture and strengthening entrepreneurial mindset
- Impacts on the residential and commercial real estate market
- Stimulating private and foreign investment
- Increasing productivity and profits and promoting competition
- Promoting innovation and digital technologies

The impact of network effects is:

- Development of social cohesion, creation of interest groups and integration
- Improving health and well-being
- Creating an attractive ecosystem and creative environment, developing urban brands and city design
- Urban development stimulation, regeneration and infrastructure
- Promoting the economic impact of clusters

C. In 2007, a study by Frontier Economics was published entitled "Side Effects of the Creative Industries – "Understanding Their Impact on the Wider Economy". The study examined the links between the creative industry and the economy as a whole and examined its effects. For this purpose, three standard overlaps have been defined, from which other effects arise, namely:

- **Knowledge transfer effects** – new ideas that benefit other companies, without charging for them, conceiving and developing these ideas within the industry and across different markets
- **Product carry-over effects** – new products that are used and produced free of charge by other companies within the industry and across markets
- **Network effects** – benefits that can only be generated in corporate networks (agglomerations and clusters)

In general, these side effects are not economically equivalent for all parties (producers and users or beneficiaries).

One of the most significant effects is the transfer of knowledge, as the cultural and creative industries are the core of the ideological economy, which primarily generates knowledge. And this production of knowledge is basically carried out under different conditions than the production of products or the creation of cooperation networks. The Frontier Economics study distinguishes between "codified" knowledge and "tactical" knowledge. Tactical knowledge is not exchanged, but determines the actions of the parties concerned. Codified knowledge is the subject of cross-sectoral communication.

To be able to generate side effects at all, stakeholders need to be active in the same field or dealing with similar topics. In this way, knowledge can be identified with ideas and can provide suggestions for simplifying production processes or for designing new business models.

The study distinguishes three basic types of knowledge effects:

- **Organizational effects - empirical evidence suggests that CI companies are organized differently than companies in other industries, e.g. flexible working hours, specific models of contracted employment based on projects, a high proportion of freelancers. However, there is no evidence so far that this has any positive impact on** the overall economy. While there are many start-ups and start-ups that have been impacted by CI, many of these companies are small or micro-enterprises, operating in innovative fringe markets.
- **Effects through the transfer of innovation -** politicians usually try to connect innovative small CI companies with larger companies from other industries, which is often not desired by CI companies because it is not in line with their corporate philosophy.
- **Effects through the transmission of entrepreneurial spirit -** the high number of start-ups in the creative industries suggests that entrepreneurial activity/entrepreneurial spirit/entrepreneurial mindset is more present here than in other sectors. Survey results show that CI entrepreneurs have a higher risk tolerance and therefore resilience to constant changes in their professional lives – which in turn may explain the higher willingness to start a business. This positive mood can also be transferred to other industries in the spirit of the motto "Entrepreneurship and success in any industry can be inspiring.

4. Discussion

The cultural and creative industries have significant spill-over effects on the wider economy and society. Added value is directly generated in them, they employ the economically active population, and cultural goods are imported and exported. The indirect economic footprint of culture and creative industries would be even higher if the creation of added value in other sectors were also taken intoaccount. The outputs of the creative work also provide inputs to a wide range of economic sectors in the form of content, inspiration, skills and competences, intellectual capital and professionals. Research by the Policy and Evidence Centre (PEC) on the multiplier effect of creative businesses over the past 20 years suggests that each creative job can generate 1.9 new jobs in local services. This means that for every single new job created in the local creative sector, almost two more jobs can be created in the wider economy. In addition to economic effects, the creative industries also have effects on wider civil society that can strengthen communities and improve individual well-being. Cultural heritage sites and local art institutions bring joy to visitors and locals, attract public funding and are a source of community pride, but their social benefits are relatively intangible and therefore difficult to measure and appreciate. (Policy and Evidence Centre 2022).

5. Conclusion

Cultural and creative industries represent a dynamic segment of the economy with significant economic, social and cultural significance, which requires special attention from researchers, public policy makers and the business sector. Its main characteristics are the emphasis on creativity as the primary production input, the strong influence of digitization, non-standard forms of employment and a high degree of interdisciplinarity. This article provided a comprehensive view of the characteristics, specifics and side effects of the cultural and creative industries. The analysis of the professional literature shows that CCI has several specific characteristics that distinguish it from other sectors of the economy. These specifics include the dominance of small and medium-sized enterprises, the significant impact of the Baumol effect on the economy of the industry, and significant spill-over effects on the wider economy and society. However, challenges persist – such as the instability of creators' incomes, insufficient representation in strategic planning or the underestimated role of culture in the development of regions. Future research and policy attention should therefore be focused on the systematic promotion of this sector, which is not only a bearer of economic profit, but also of social and cultural capital.

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Does Trust at Work Enhance Autonomy and Productivity? A Quantitative Test Using Jamovi

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Abstract: In the context of evolving organisational models such as holacracy and agile management, trust and autonomy are increasingly recognised as drivers for productivity and innovation in modern workplaces. This article examines whether higher perceived trust within an organisation is positively associated with feedback culture and self-perceived productivity. Using a quantitative research method, data were collected through a structured questionnaire assessing a number of factors surrounding workplace dynamics. Results were interpreted based on a 5-point scale. Composite indices were created for Trust, Feedback & Productivity, and a linear regression analysis was conducted using Jamovi statistical software. The analysis identified a statistically significant positive relationship between perceived workplace trust and feedback/productivity levels ($\beta = 0.451$, $p < .00001$), with the model explaining approximately 20% of the variance (Adjusted $R^2 = 0.200$). Assumption checks supported the model's validity, confirming acceptable normality, no multicollinearity, and no autocorrelation. These findings indicate that fostering trust within the workplace can serve as a powerful driver of employee motivation, autonomy, and overall performance, highlighting the growing prominence and practical relevance of decentralised management models in today's organisational landscape.

Keywords: workplace trust; employee autonomy; productivity; feedback culture; holacracy; decentralisation; Jamovi; linear regression

Introduction

The nature of work environment is undergoing a profound transformation, driven by increasing complexity, rapid technological change, and evolving expectations of the modern workforce. Organisations are urged to rethink traditional management structures as a response to the paradigmatic shift. Innovative management structures, such as holacracy, agile teams, and flat hierarchies are emerging as alternatives to rigid, top-down hierarchies. These approaches prioritise decentralisation, autonomy and collaboration to enhance company adaptability and organisational resilience in the fast-paced business environment. Understanding the enablers of self-management and decentralised work thus becomes critical not solely for organisational performance, but also for employee satisfaction and engagement.

Two fundamental factors often cited as key to the success of such modern systems are trust and feedback culture. Trust fosters autonomy and initiative, while feedback culture supports continuous improvement and individual growth.

Although innovative management styles have been researched theoretically and qualitatively globally, there is a noticeable lack of quantitative research in the Slovak context, especially when it comes to assessing the combined impact of trust on productivity and self-management in non-hierarchical environments. Moreover, in general there is limited data on Slovak firms actively implementing decentralised management structures, through emerging trends suggest that some companies are moving in this direction. This research thus represents a small but important part of a broader inquiry into the existence, readiness, and potential impact of modern management structures on Slovak businesses, contributing valuable insight to the national discourse on organisational innovation. This study aims to address the existing gap by employing a structured statistical approach to examine how perceived trust influences feedback culture and productivity within workplace settings.

1. Literature Review

The changing nature of work and management has given rise to a wave of innovative organisational approaches that challenge traditional hierarchical models. Such concepts as holacracy, flat hierarchies and agile teams are emblematic of this paradigmatic shift, emphasizing decentralisation, flexibility, innovation, and employee empowerment (Farkhondeh & Mueller, 2021; Purusothaman, 2019). These models reflect a broader movement, represented by a shift away from rigid, top-down control and towards more dynamic, responsive and flat organisational cultures. One of the earliest movements to challenge traditional hierarchical management was post-bureaucracy, which emerged as a response to inefficiencies and limitations of bureaucratic structures. Post-bureaucracy brought decentralisation and collaboration to the forefront of organisational design (Heckscher, 1994), promoting structures that enable knowledge sharing, innovation, and employee engagement.

Among the most prominent contemporary approaches is holacracy, a decentralised organisational framework, which has emerged as an alternative to traditional hierarchical models. Robertson (2015) describes holacracy as a governance model that refines traditional roles and distributes authority across self-managing teams. By doing so, the concept encourages participative decision-making and greater transparency in organisational dynamics. Moreover, the concept seeks to improve adaptability and foster self-organisation within the increasingly complex business environment (Farkhondeh & Mueller, 2021). Furthermore, research suggests that such organisational structure can also reduce transaction costs and shift reward systems in ways that align more closely with collective outcomes (Romero & Freitas, 2022).

Central to these contemporary managerial approaches is the recognition of autonomy and self-management as key drivers of organisational effectiveness and employee satisfaction. Research increasingly supports the view that when employees are granted autonomy, they exhibit higher levels of motivation, creativity, and job satisfaction, a combination which contributes to improved overall performance (Alexandrino et al., 2024; Ryu et al., 2020). As the business environment becomes more complex and dynamic, the ability of organisations and teams to self-organise and adapt has become not just beneficial, but essential.

To successfully keep up with the pace of the business environment and implement decentralised management approaches, it is critical to examine other key enabling factors that support their effectiveness. Among these, trust, feedback, decision-making and productivity emerges as core pillars that shape the functionality and sustainability of decentralised work environments.

1.1 The role of trust and autonomy

Research on decentralisation and emerging management innovations repeatedly point to the foundational role of **trust** within organisation (Dovey, 2009; Ellonen et al., 2008; Lazányi, 2017; Tyler, 2003).Trust facilitates autonomy by allowing employees to operate with greater independence and confidence in systems where hierarchical oversight is reduced. It is positively associated with employee's willingness to take initiative and pursue innovations, and as a result promotes idea generation, promotion, and implementation (Jønsson et al., 2020). Covey and Merrill (2006) describe trust as one of the most underutilised assets in professional settings, with the power to enhance both organisational and professional performance. Numerous empirical studies reinforce this viewpoint. Studies across various countries suggest that societal trust correlates strongly with the level of work autonomy offered by employers (Hoorn, 2013). Moreover, Heyns and Rothmann (2017) found that trust predicts autonomy satisfaction, which in turn mediates the relationship between trust and employee engagement. In agile team settings, trust and team autonomy are identified as key drivers of work engagement and team effectiveness (Buvik & Tkalich, 2022).

1.2 Autonomy, feedback and productivity

While trust lays a strong foundation, feedback culture is just as essential in order to sustain decentralised management. According to the Self-Determination Theory (Ryan & Deci, 2017), autonomy, competence and relatedness are psychological needs of individuals that foster motivation and engagement. An active feedback culture supports the development of competence by helping individuals and teams adjust, grow, and align with company goals, while reinforcing a sense of value and contribution. Moreover, feedback enhances not only the communication flow within a team, but also drives performance outcomes (DeShon et al., 2004). When feedback is regular, constructive and is implemented in the team culture, it promotes continuous improvements (Stup, 2019), fosters collaboration (Kim & Pentland, 2009), and strengthens self-management (Nicol, 2019). These aspects make feedback a crucial enabler of effective decentralised management.

Building on these conceptual foundations, this research aims to examine the relationship between trust at work and feedback & productivity levels – two key enablers of decentralised management. By testing the hypothesis that higher workplace trust is positively and statistically significantly associated with feedback culture and productivity, the research contributes to a data-driven understanding of the readiness for decentralised management. Although in Slovak context limited quantitative data exists on the research topic, this article begins to fill this research gap.

1.3 Hypotheses

The following section outlines the hypothesis formulated based on insights from the literature review and relevant theoretical considerations.

H_0: There is no statistically significant relationship between trust at work and feedback & productivity levels.
H_1: There is a positive and statistically significant relationship between trust at work and feedback & productivity levels.

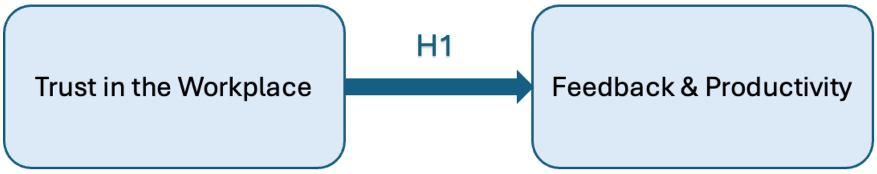

Figure 1. Conceptual framework of the research

Source: Own proceedings

The conceptual framework in Figure 1 explains trust as an active driver of feedback culture and productivity levels. It illustrates the theoretical basis for the hypothesis (H_1) that trust at work is positively and significantly related to feedback and productivity. By fostering open communication and psychological safety in a work setting, trust is expected to encourage a strong feedback culture and higher performance outcomes.

2. Methodology

In the following section we outline the applied methodology, along with the sample, data collection and statistical procedures used. In order to test the hypothesis, we conducted a quantitative study with survey data from professionals working in various fields in Slovakia.

Table 1. Description of respondent's demographics

Research Component	Options	Data
Sample size	-	n=236
Gender	Male	47 %
	Female	52.5 %
	Other / I don't want to share	0.5 %
Age range	18 – 24	33.5 %
	25 – 34	29.7 %
	35 – 44	13.6 %
	45 – 55	18.2 %
	55 +	5 %

Industry	Banking, Finance and Insurance Sector	19.9 %
	Consulting Sector	14 %
	IT and Telecommunication Sector	12.7 %
	Healthcare and pharmacy Sector	1.7 %
	Education Sector	3 %
	Construction and Architecture Sector	3.4 %
	Transport and Logistics Sector	8.1 %
	Manufacturing Sector	11.4 %
	Retail and SMEs Sector	10.2 %
	Marketing, Media and Creative Sector	3.4 %
	Law and Legislative Sector	0 %
	State administration and Public Sector	3 %
	Agriculture Sector	0.4 %
	Science, Research, and Innovation Sector	0.8 %
	Non-Profit Sector	0.8 %
	Other Sector	7.2 %

Source: Own proceedings based on survey results

Participants were recruited through a combination of convenience and snowball sampling. University students were invited to support data collection by submitting contact details for potential participants in exchange for extra course points, while additional contacts were sourced through the researcher's professional networks and workplace affiliations. The questionnaire was distributed electronically via email, with all participants informed of the voluntary and anonymous nature of their participation. A total of 236 responses were collected from individuals representing diverse organisational sectors. The sample consisted of 52.5% female and 47% male respondents, with 0.5% choosing not to disclose their gender. In terms of age distribution, 33.5% of respondents were aged 18-24, 29.7% were 25- 34, 13.6% were 35-44, 18.2% were 45-55, and 5% were 55 or older. Industry representation was led by the Banking, Finance and Insurance sector (19.9%), followed by Consulting (14%) and IT and Telecommunication sector (12.7%).

The questionnaire encompassed a broad set of research items focused on workplace dynamics. For the purpose of this article, only a selected subset of items was analysed, specifically those relevant to the hypothesis. These were grouped into two thematic categories: Trust and Feedback & Productivity.

Trust in the workplace was measured using four items related to perceived team trust, decision-making efficiency, productivity and resilience in uncertain situations. Feedback & Productivity was evaluated using five items that addressed the feedback culture, team collaboration, independent working and creative freedom. Responses were interpreted using a 5-point Likert scale ranging from 1 ("Strongly disagree") to 5 ("Strongly agree"). Composite indices were calculated for both thematic clusters, resulting in two variables: Trust Index and Feedback & Productivity Index.

The **Trust Index** was calculated by combining responses to the following statements:

- There is trust in my workplace;
- The greater the trust in the team, the faster the decision-making process;
- Higher trust in my workplace leads to greater productivity;
- Greater trust within the team increases the ability to cope with unforeseen situations.

The **Feedback & Productivity Index** was created from responses to these statements:

- The feedback culture in my workplace positively impacts my performance at work;
- Positive and constructive feedback prevails in my team/group/department;
- Regular feedback improves team collaboration;
- Feedback enhances the ability to work independently without hierarchical supervision;
- I am most productive and creative when I have the freedom to try new ideas at work.

These composite indices were computed using Jamovi by averaging the scores of relevant items. To test the hypothesis, a linear regression analysis was conducted with the Feedback & Productivity Index as the dependent variable, the Trust Index as a covariate. Before conducting the analysis, standard assumptions were assessed to ensure the validity of the model, including checks for the normality, absence of multicollinearity, and independence of errors. The assumptions were considered sufficiently met given the robustness of linear regression with larger sample size.

3. Results and Discussion

The following section presents the findings from the statistical analysis conducted to test the study's hypothesis. The results explore the relationship between trust at work and levels of feedback and productivity, based on a data collected from 236 respondents across various sectors within Slovakia. The analyses include descriptive statistics, reliability of the indices, and linear regression analysis to accept or reject the hypothesis.

3.1. Results of Linear Regression analysis in Jamovi

Table 2. Model Fit Measures[1]

				Overall Model Test			
Model	**R**	**R^2**	**Adjusted R^2**	**F**	**df1**	**df2**	**p**
1	0.451	0.203	0.200	59.6	1	234	<.00001
[1] Note. Models estimated using sample size of n=236							

Source: Own proceedings in Jamovi

The linear regression analysis revealed a moderate positive correlation between trust and feedback & productivity, as indicated by R = 0.451. The model explains approximately 20.3% of the variance in feedback and productivity scores (R^2 = 0.203), with the adjusted R^2 = 0.200 accounting for sample size and model complexity. The overall regression model was found to be statistically significant (F(1, 234) = 59.6, p < .00001), suggesting that trust is a meaningful and significant predictor of feedback and productivity levels in the workplace.

Table 3. Model Coefficients - Feedback & Productivity Index

Predictor	**Estimate**	**SE**	**t**	**p**	**Stand. Estimate**
Intercept	1.875	0.2886	6.50	<.00001	
Trust Index	0.601	0.0778	7.72	<.00001	0.451

Source: Own proceedings in Jamovi

The regression coefficients further support the significance of the relationship between trust and feedback & productivity. The intercept is 1.875, representing the baseline level of feedback and productivity when trust is zero. However, this value holds limited interpretability in practice. The coefficient for the Trust Index is 0.601 (SE = 0.0778, t = 7.72, p <.00001), indicating that each one-point increase in trust is associated with a 0.601-point increase in the Feedback & Productivity Index. This relationship is both positive and statistically significant. Additionally, the standardised estimate (β = 0.451) represents a moderate effect size, further confirming the meaningful impact of trust on workplace performance outcomes.

Assumption Checks

Table 4. Durbin–Watson Test for Autocorrelation

Autocorrelation	DW Statistic	p
0.0432	1.91	0.51200

Source: Own proceedings in Jamovi

Table 5. Collinearity Statistics

	VIF	Tolerance
Trust Index	1.00	1.00

Source: Own proceedings in Jamovi

Table 6. Normality Test (Shapiro-Wilk)

Statistic	p
0.915	<.00001

Source: Own proceedings in Jamovi

The regression diagnostics indicate that the assumptions of the linear regression were adequately met. The Durbin-Watson statistic of 1.91 indicates no autocorrelation in the residuals, falling within the acceptable range of 1.5 to 2.5. VIF = 1.00 and Tolerance = 1.00 confirm that there is no multicollinerity, which is expected given that only one predictor (Trust Index) was included in the model. The Shapiro-Wilk test ($p < 0.00001$) indicates that the residuals deviate from a perfectly normal distribution.

We reject

H_0: There is no statistically significant relationship between trust at work and feedback & productivity levels

and accept

H_1: There is a positive and statistically significant relationship between trust at work and feedback & productivity levels.

Trust in the workplace statistically significantly influences feedback and productivity levels, with adjusted $R^2 = 0.20$; $F(1,234) = 59.6$; $p < 0.00001$, and standardised Beta = 0.451.

Regression equation:

$$\boldsymbol{Y = b_0 + b_1 * X + e} \tag{1}$$

Feedback & Productivity Index (Y)= $\mathbf{1.875 + 0.601} * \boldsymbol{Trust\ Index}$

where
X = score of predictor, in our case the Trust Index
Y = dependent variable, in our case the Feedback & Productivity Index
e = error

5. Conclusion

This research paper examined the relationship between workplace trust and feedback culture and self-perceived productivity, within the broader context of decentralised and innovative management models. Focusing on workplace autonomy, organisational design, and other workplace variables, this research contributes empirical evidence to an area currently underexplored in the Slovak context.

The results of the linear regression analysis indicate a statistically significant and positive realtionship between trust at work and feedback & productivity levels ($\beta = 0.451$, $p < .00001$), with the model accounting for 20% of the variance (Adjusted $R^2 = 0.200$). These findings support the rejection of the null hypothesis and validate the alternative hypothesis, confirming that trust is a meaningful predictor of performance-related outcomes in work settings.

The findings carry important implications for organisations aiming to implement more agile or self-managed structures. Trust emerges as a key enabler of effective decentralisation, facilitating autonomy, encouraging feedback culture and enhancing employee engagement. This study provides an important step towards a deeper understanding of the shifting nature of organisational management towards decentralisation.

Future research should further explore the shift towards innovative mangerial styles and their interplay with trust-building practices, as well as examine how these evolving approaches influence long-term organisational performance and employee-well being. Additionally, incorporating other variables in the analysis – such as employee autonomy, decision-making processes or leadership dynamics – could provide a more comprehensive understanding of the shifting nature of organisational management.

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The use of the Black-Scholes model in evaluating a specific strategic opportunity of a creative industry enterprise

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Abstract: Business in the creative industries combines a high degree of uncertainty with the possibility of above-average returns, with the key to success being expert management of intangible assets, diversified financing and a proactive innovation strategy. Copyright protection, flexible project management and sophisticated valuation procedures form the pillars of both the sustainable development and competitiveness of these businesses. The natural synergy of cultural value and economic return makes the creative industries a unique field that requires specialized approaches in both business economics and intellectual property law. We therefore consider it essential that multiple methods and approaches are used in the evaluation process, which requires the use of consistent metrics and indicators. The use of multiple methods provides opportunities to make rational choices about the ultimate value of the business and the factors that influence it.

Keywords: creative industries; enterprise value; valuation methods

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Introduction

In a period characterized by the increasing globalization of recent decades, we are witnessing an extremely dynamic trajectory of economic development (Artikis et.al.,2022). This expansion is accompanied by massive capital inflows to an increasing number of countries engaging in the process of globalization. These phenomena are inextricably linked to the growing need for enterprise valuation (Stryjakiewicz et.al.,2014). Knowledge of enterprise value is very important for the internal environment of the enterprise and especially for the strategic decisions of the enterprise (Miciula et.al. 2020). Banks, business partners, customers, financial analysts and government authorities are also recipients of enterprise value information.

Enterprise valuation is a complex problem that requires an interdisciplinary approach (Damodaran, 2016). The value of a firm is influenced by a number of variable factors such as the macroeconomic environment of the country, the nature of the business and the industry in which the firm operates, the attractiveness of the market, the nature of asset utilization, the quality of human resources, the strategic objectives of the firm, etc. (Van de Schootbrugge et.al.,2013). Despite the large number of academic and scientific studies devoted to this topic, there are still many unsolved academic and technical problems, and this area is associated with a number of controversies and trade-offs (Machala,2009; Husák et.al.,2021). A particular challenge in this context is the valuation of cultural and creative industries (CCIs) enterprises (see below) (Wright,2018; Granger,2020). Small and medium-sized enterprises make up the dominant part of these. These are widely regarded as the engine of economic growth. They contribute to job creation and economic growth and provide social stability, stimulate innovation and entrepreneurship, and are essential for promoting competitiveness and employment across the EU.

1. Literature Review

The valuation of CCIs differs from that of large corporations due to their unique characteristics. According to current academic studies and publications, these are mainly the following specificities of their entrepreneurial dimension:

1. Intangible assets and intellectual property rights are the dominant component of their assets Chang, 2012) Especially in such industries as publishing houses, film studios, design companies, software firms, copyrights, trademarks, know-how and designs form the dominant part of their asset value. The valuation of these assets requires specific methodologies (income capitalisation method, market transactions or real options). The use of accounting data does not give a fair picture of the value of these assets and does not reflect their ability to generate future income.

2. CCI companies operate in a volatile market that is characterized by instability and uncertainty, rapid changes in demand, trends in the relevant CCI industry, and rapid changes in the technologies used (Candace et.al.,2015). Businesses in the creative industries need to continuously invest in science and research, technological innovation (artificial intelligence, digital distribution, etc.), and training of their employees. Thus, innovation capability becomes a key indicator of their competitiveness. Often a hybrid combination of internal teams (e.g. design, software development, etc.) and external open-innovation partnerships (universities, startups, research institutions, etc.) is used. (Londar et.al.,2020) In this model, it is necessary to address risk sharing between partners, licensing agreements with external partners, joint ownership of intellectual property rights, etc.

3. The success and competitiveness of a CCI enterprise depends extremely on the talents and skills of the people working in it, such as designers, artists, musicians, etc. Valuation must therefore also reflect the value of human capital (Escaith, 2022).

However, this value is not captured in the accounts. In the creative industries, a flat organisational structure prevails and agile methodologies, multifunctional teams (members with different professional qualities) are used, which makes it possible to create and manage complex and dynamic projects.

4. In CCIs, revenue streams are non-standard and diversified (royalties, license fees, subscriptions, etc.). Many times, these are one-off revenues, e.g. for an artwork, a software licence. These revenues are often uncertain and dependent on the specific success of the work in question. In contrast, licence, sub-licensing, and royalty payments can be regular income. These facts affect the value of a given business entity and the valuation methodology for creating discounted cash flows must respond to these specifics (Remenova et.al.,2023).

5. Cultural and social factors of CCIs significantly influence pricing (trends in art, entertainment, fashion, etc.), which has a significant impact on demand and therefore on the value of the business (Remeňová et.al.,2023). The demand in KKP is very sensitive to brand reputation, reviews, and media coverage. Therefore, different price differentiation tools are used in pricing such as VIP tickets, limited editions, etc.

6. Diversified sources of capital, which result from the fact that KKP enterprises use, in addition to their own capital and bank loans, public grants from the state and EU budgets, private investment funds, crowdfunding and also systems based on altruistic motives of individual natural and legal persons.

7. The risk profile of CCIs, which results from the uncertainty in predicting future revenues (success/failure, changing consumer tastes, fashion trends, etc.). The risk also stems from the low enforceability of the law in case of infringement of intellectual property rights (e.g. copyright).

CCIs are characterised by specific problems that are primarily linked to the possibilities of raising capital and therefore to the possibilities of managing the value of the business entity. However, it is often not possible to rely on capital market share values to manage their maximum value to the owner and it is necessary to look for compromise solutions when applying alternative methods of measuring and managing value, such as discounted cash flow with adjusted WACC, market-based transaction method or multiples, Relief-from-Royalty (ROR), Multi-Period Excess Earnings Method (MPEEM) , Real Option Valuation (ROV)or equity (Shepeleva, 2016) . The application of these alternative methods increases uncertainty in enterprise value management, mainly due to the need to accept subjective judgment in determining the basic parameters of these methods, such as cash flow projections, expected growth rates or capitalization rates. Further complications arise from the time and financial resources required to implement such complex processes (Mařík et.al.,2018).

As mentioned above, determining and managing the enterprise value of KKP is an interdisciplinary problem with many specific challenges. We are of the opinion that there is no universal valuation method. Moreover, in the current scientific discourse, there is a growing number of questions regarding the credibility and robustness of enterprise valuation metrics (McKinsey et.al.,2010; Damodaran, 2012; Majduchova et.al., 2017). The issue of trust crisis in this field is complex and multidimensional, affecting various areas including business decisions, investment strategies and regulation.

It should be noted that the scientific literature dealing with the problems of valuation of CCI enterprises is rather scarce.

Research in this area aims to fill an important critical research gap in the area of valuation of cultural and creative industries enterprises.

2. Methodology

In this paper, we want to focus on a more detailed characterization of the valuation method of a creative industry enterprise, namely the method in which each investment opportunity is modeled as an option using the Black Scholes equations. This method is particularly suitable in those creative industries where creative projects go through decision-making phases, with a decision to continue or terminate the project at each phase. This method is particularly appropriate in those creative industries where creative projects go through phases of decision-making, with a decision at each phase to continue or terminate the project. This method is particularly practical for large-scale audiovisual projects (blockbusters - films with extraordinary budgets and massive marketing), digital and VR/AR projects, game studios, video games, fashion, design services where there is high uncertainty in future revenue generation. This method is also suitable for startups and innovative businesses as it has the ability to reflect on uncertainty and future opportunities. We anticipate that it will offer a more realistic view of enterprise value than traditional methods.

The method is based on the real options method. This method complements the DCF method by considering the strategic decisions that the enterprise is considering making in the future . The option value is realised using the Black Scholes Model (BSM). [20] Although this model represents a certain idealistic notion of future value, its formulation remains fundamental to the understanding of risk-neutral valuation.

The BSM model is based on the following assumptions:

1. A risk-free interest rate that is constant over the life of the option.
2. The price of the asset (stock, project, enterprise) follows a geometric Brownian motion, i.e., it has a lognormal price distribution.
3. There are no transaction costs and fees, i.e. trades are free of fees, spreads.
4. Options are of European type - they can only be exercised on the expiration date.
5. Unlimited put option - investor can borrow and sell the underlying asset without any marginal requirements.
6. Absence of dividend payments - the underlying asset does not pay dividends or other regular income during the life of the option.

Call option price (the right to buy an asset at a specified price in the future):

$$C = S_0 N(d_1) - X e^{-rt} N(d_2) \tag{1}$$

Put option price (the right to sell the asset at a specified price in the future):

$$P = X e^{-rt} N(-d_2) - S_0 N(-d_1) \tag{2}$$

$$d_1 = \frac{\ln\left(\frac{S_0}{X}\right) + \left(r + \frac{\sigma^2}{2}\right) t}{\sigma\sqrt{t}} \qquad d_2 = d_1 - \sigma\sqrt{t} \tag{3}$$

Where:

S0 - the current price of the underlying asset (e.g. the value of the business)

N (d) - the value of the cumulative distribution function of the normal distribution

X - option strike price (exercise price, strike price)
r - risk-free interest rate (e.g. government bond yield)
P - put option value
C - value of the call option
t - time to expiration of the option in years
ẟ - volatility of the price of the underlying asset (standard deviation of annual returns)

In the context of business valuation using the Black Scholes model, it is not a traditional determination of the value of a business, but the valuation of a specific strategic option (a real option). The model will determine the ability of the option to increase the present value by the flexibility of the business.

Interpretation of the formula

N(d1) expresses the fact of how the change in the price of the asset affects the value of the option today, i.e. if the price of the underlying asset changes by €1, the value of the option will change by €N(d1).

N(d2) and are the probabilities that the option will be "in-the-money", i.e. that it will be profitable to exercise it, i.e. that the price of the underlying asset will be higher than the strike price at expiration.

S0N(d1) represents the expected future value of the asset discounted by the probability that the option will be in-the-money.

Xe-rtN(d2) is the discounted exercise price of the option weighted by the probability of exercise. The symbol e represents the Euler number (e≈2.71828).

In implementing the Black-Scholes model, the following problems have to be dealt with:

1. (S_0) to be considered the present value of the business? This is an input variable that must be determined using other methods such as DCF, market multipliers, etc. With some simplification, it can also be the book value of equity.
2. (X) How to determine the investment cost of expansion? For example, it may be the cost of building new technical facilities, the cost of acquiring a licence, the cost of developing and implementing a new product, the cost of marketing and distribution, the cost of innovation, etc. A prerequisite is to determine what the enterprise considers to be expansion and then to draw up an investment budget for it, which includes capital expenditure (CAPEX), working capital costs (NWC), operating costs. These capital expenditures are not expected to be spent all at once but over a period of time determined by the enterprise, i.e. they need to be discounted using either r.
3. (t) How to determine the time during which the enterprise has the opportunity to exercise a strategic decision (e.g. to invest, expand, postpone a project, enter a new market or exit an investment). This is therefore an informed managerial decision which may be based on the enterprise's internal plans, market constraints and possible regulations, technological developments, market life cycle, licence expiry time, etc. It is therefore a question of 'How long is the strategic opportunity likely to exist?' The shorter the time, the lower the value of the option will be because the time value of the option decreases.
4. (σ) How to determine volatility? Volatility in the Black Scholes model expresses the uncertainty that the future about future values or cash flow. Several approaches can be used to determine it. There are typical volatility ranges by sector (Investupedia, Fidelity Investments, Macrosynergy, etc.) Another option is to find 3-5 comparable publicly traded companies, obtain historical data on their stock prices, calculate daily or weekly log returns, and determine the standard deviation of the returns, annualize it, and average the results. Another method is to use accounting data on cash flow, EBITDE, or sales, calculate year-over-year percentage changes, and then calculate the standard deviation of growth. Volatility can also be determined based on expert judgement. The higher the volatility, the greater the time value of the option, as the chance that it will be profitable increases.
5. (r) This is the risk-free interest rate, which is applied as the rate on government bonds whose maturity corresponds to time t. ECB/NBS data, euro swap rates, government bond yields, etc. can be used as a source.

3. Results

In the next section of our paper, we show a practical implementation of the Blac-Svhles model using a case study, while also pointing out its risks and shortcomings.

Let us choose a business entity whose business is media. The entity is considering entering a new market with its own streaming services. Management has the opportunity to invest €3 million in expansion over 3 years. The company is currently worth € 6 million. What is the value of the expansion option, i.e. will the company's decision to expand be a valuable asset even if the investment has not yet been made?

S0 = €6 million

X = €3 million

T = 3 years

r= 3,3%

We determine σ = volatility according to sectoral volatilities, which is in the range of 35-60% in the media sector, and we set it at 60% because of the high attractiveness of expansion.

Calculation of the expansion option price:

d1=ln (6 000 000/3 000 00) +(0.033+0.62/2)3/0,6x3

d1 = 1,3321/1,0392

d1 = 1,282

N(d1) = 0.8997, this is the probability of a normally distributed variable taking a value less than or equal to 1.281, is approximately 89.99%.

d2 = 1,281 -1,0392

d2 = 0,243

N(d2) = 0,5961

C= 6 000 000x 0.8997-3 000 000e-0.033*3x 0.248

C= 5 399 400-2 717 228,12*0,5961

C= 3 778 460,31

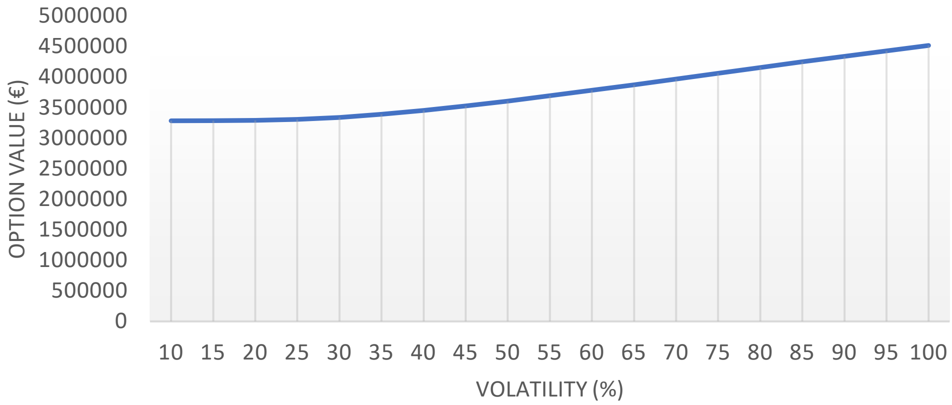
The result of the calculation shows that the expansion option is worth approximately 3,778,846.31 is the amount that an investor or manager should be willing to pay for the opportunity to expand the project in the future, not immediately.

4. Discussion

The expansion option is greater than the investment cost, i.e. the business can acquire a valuable asset. The expansion option (real option) represents additional flexibility - for example, if market conditions improve, the firm can expand the project, and €3.78 million is the economic value of this flexibility, which is not accounted for by conventional methods such as DCF.

The result obtained is largely influenced by the relatively high volatility of strategic expansion. In the following graph we show the sensitivity of the value of the expansion option to volatility. The difference between 10% and 100% volatility amounts to €1,232,464.

Figure 1. Sensitivity of the option value to volatility



Source: own elaboration

We therefore recommend using a number of the approaches we have already outlined in section 4 to determine volatility.

The Black-Scholes model is an important and widely used model in the valuation of option expansions, but it has several limitations and risks that can lead to inaccurate results, especially in real market conditions. The model assumes a constant volatility, risk-free interest rate, but which can change over time. Also, the model assumes that logarithmic returns follow a normal distribution, but in reality, this may not be the case and extreme price movements occur frequently. The model also assumes that markets are efficient, with continuous trading. The model can also fail during extreme fluctuations (e.g. during robust financial or economic crises).

5. Conclusion

Despite the fact that the BSM model is being used, we have also pointed out its shortcomings and limitations. It is therefore necessary to consider alternatives to this model, e.g. a binomial model that decomposes time into discrete steps, or the use of the Motle-Carlo method, etc. However, in view of the fact that these are sophisticated mathematical models, it is necessary to consider the effectiveness of their use. We recommend the use of this model as a complementary method in the valuation of a cultural and creative industry company, especially in cases where traditional valuation models do not reflect the future strategic opportunities of the company, which could significantly affect the level of its value.

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The Omnibus Directive Simplification and its Impact to ESG Corporation Management

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Abstract: Basic description of the corporate ESG management and related ESG reporting are obligations under the Corporate Sustainability Reporting Directive, Corporate Sustainability Due Diligence Directive, and the EU Taxonomy Regulation. Performance of Corporate risk management for the Double materiality assessment. Research Design: All research activities during the whole investigation period were carried out based on the application of the three-dimensional perspective logic of the research process: research aims, object of the research, methodology of the research.

Keywords: ESG management; ESG reporting; Omnibus directive

Introduction

The Omnibus directive of the EU promises to reshape the corporate ESG management and related ESG reporting landscape by consolidating multiple sustainability-related requirements into a single, streamlined framework. Announced by European Commission President Ursula von der Leyen in November 2024, the regulation aims to simplify the often-overlapping obligations under the Corporate Sustainability Reporting Directive (CSRD), Corporate Sustainability Due Diligence Directive (CSDDD), and the EU Taxonomy Regulation. The agreed Omnibus directive, is setup to reduce bureaucracy without compromising on content, ensuring businesses operating in EU member states can focus on compliance while driving sustainability. This article unpacks the Omnibus package simplification and its impact to corporation ESG management and related ESG reporting. Omnibus Simplification Package related to the ESG Reporting Changes: CSRD, EU Taxonomy, CSDDD.

1. Overview of the Current Attribute of ESG Management and Reporting

Companies operating in the European Union have started to solve the non-financial and sustainability reporting requirements starting January 2024 with the EU's CSRD. The CSRD advancement shows a change in how governments are regarding the reporting of ESG data, which include a company's carbon emissions. ESG reporting is crucial in helping stakeholders, particularly investors, evaluate the risk of their investments by knowing the company's impact on the people and the planet. It also helps them understand how climate change disasters can impact the business. Robust sustainability reporting is also vital in establishing trust and enhancing a company's reputation. We can identify positives and benefits of ESG reporting according to the European Sustainability Reporting Standards (ESRS):

- Attracting investment based on ESG reporting
- CSRD – the framework on the sustainable path
- Reduced cost of ESG reporting, and fewer data requests
- Leading position in the global competition through common reporting standard across the EU
- CSRD makes it easier to understand the ESG impacts of the supply chain
- Prevents greenwashing and voices sustainability results (https://www.csrdsoftware.com/, 15/05/2025)

Relevant legislation for ESG management and reporting we have in comprehensive form:

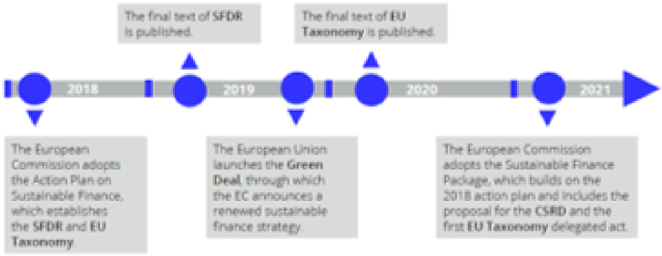
RELEVANT EU REGULATIONS RELATED TO THE ESRS STANDARDS	
Regulation	**Description**
European Sustainable Finance Action Plan (ESFAP)	In recent years, the European Union has formed multiple initiatives to connect finance and sustainability through the 2018 Action Plan on Sustainable Finance; the Green Deal, which includes the EC's renewed sustainable finance strategy; and the Sustainable Finance Package. The graphic below illustrates the timeline of the developments in recent years. 
Non-Financial Reporting Directive (NFRD)	The NFRD was adopted in 2014 and requires large public-interest companies that have more than 500 employees and are listed within the European Union to provide nonfinancial disclosures related to ESG matters along with their annual financial reports.The CSRD replaces and expands the existing requirements of the NFRD and extends the scope of companies required to disclose sustainability information from approximately 11,700 to 50,000 companies in the European Union, with another 3,000 or more US - based companies estimated to be affected. Ultimately, the scope of the CSRD may be affected by how each EU member state transposes it into law.
Sustainable Finance Disclosures Regulation (SFDR)	The SFDR requires certain financial market participants and advisors to provide transparency in sustainability reporting on (1) the ESG qualities of the financial products that are offered to their clients as part of existing precontractual and periodic disclosure obligations, and subsequently reflected on their Web sites, and (2) how they incorporate sustainability matters into their investment decisions. These requirements, which are in addition to those of the CSRD, apply to financial market participants that offer investment products in the European Union, financial advisors who guide E.U. consumers, and non-E.U. financial institutions operating in the European Union or transacting with E.U.-based clients.
Corporate Sustainability Reporting Directive (CSRD)	The CSRD seeks to standardize non-financial reporting by companies, enhancing the consistency and quality of publicly available data. Notably, these new standards will impact a vast array of organizations, are coming into effect on January 1, 2024. It will require defined companies to publish non-financial reports in accordance with standards established at the European level (ESRS). Detailed information on risks, opportunities, and material impacts related to social, environmental, and governance issues is expected. Generally speaking, it seeks to fulfill the ambitions of the European Green Deal - by achieving carbon neutrality by 2050.
European Sustainability Reporting Standards (ESRS)	What ESRS require: Altogether there are 12 ESRS guidelines based on ESG pillars. Two, ESRS 1-2, are general and valid for all firms meeting the CSRD criteria. Five standards, ESRS E1-5, deal with the environment. Four standards, ESRS S1-4, discuss the social pillar. Responsibility in company management and business conduct is addressed by one standard, ESRS G1. According to specific standards (5 E, 4 S, 1 G), those companies that recognize the given areas as significant will have to report. Their choice of materiality will be subject to assurance through an independent external auditor. An innovative element of the European standards for sustainability reporting is the so-called double significance. Companies will have to evaluate not only how the environment affects their business, but also how their business affects the environment. An example could be a lack of water. The company will assess how important this deficiency is to its profitability (financial significance), but at the same time how significantly its business has affected the quality of water resources (significance in terms of impact).
EU Taxonomy for Sustainable Activities	The EU Taxonomy for Sustainable Activities, also known as the "EU Taxonomy," is a classification system that establishes a list of environmentally sustainable economic activities that are consistent with the six environmental objectives pursued in the European Union as well as minimum social and human rights safeguards. The EU Taxonomy provides entities, investors, and policymakers with appropriate definitions and criteria (including science-based technical criteria) with which to identify economic activities that can be considered environmentally sustainable. While aiming to create security for investors and protect private investors from greenwashing, the EU Taxonomy also (1) helps companies become more climate-friendly, (2) mitigates market fragmentation, and (3) promotes a shift in investments to where they are most needed. The EU Taxonomy allows entities to comply with the EU Taxonomy Regulation (Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088) which establishes six environmental objectives:  The CSRD ties into Article 8 of the EU Taxonomy Regulation by requiring companies to report various key performance indicators, which vary on the basis of the nature of the entity, with respect to all six environmental objectives. For example, a company within the scope of the CSRD will be required to report its turnover, capital expenses, and operational expenses with respect to all six environmental objectives.
Corporate Sustainability Due Diligence Directive (CSDDD)	Currently in development, the CSDDD is a future E.U. directive that would introduce required due diligence steps that companies must follow regarding human rights and environmental impacts. The directive would require companies to identify and remediate any negative human rights and environmental impacts within their own operations as well as those of their subsidiaries and up and down their value chains. The goal of the CSDDD is to encourage sustainable and responsible corporate behaviour and operations. While these requirements would be in addition to those of the CSRD, there may be a number of synergies between the two directives, such as on the disclosure of value chain impacts and transition plans and the requirement to have a climate transition plan aligned with the Paris Agreement.
European Green Bond Standard	The European Green Bond Standard is another regulation in development, which will possibly be finalized in 2023. It is a voluntary standard to help scale up and raise the environmental ambitions of the green bond market. Applying this standard would allow issuers to demonstrate that they are funding legitimate green projects aligned with the EU Taxonomy. The EU Green Bond Standard sets out requirements that would enable companies to claim that they are issuing an "EU green bond," a label that is expected to be sought by the financial sector, which aims to invest in sustainable investments. Entities that do not follow the EU Green Bond Standard would not be entitled to claim that they are issuing "green bonds." The requirements of the EU Green Bond Standard include references to the EU Taxonomy.

Figure 1. ESG reporting standards in the EU

Source: Self-elaboration according to he https://www.efrag.org/,15/05/2025

The transformation from previous ESG reporting methods (e.g. GRI) into the ESRS according to the CSRD is presented in next Figure 2.:

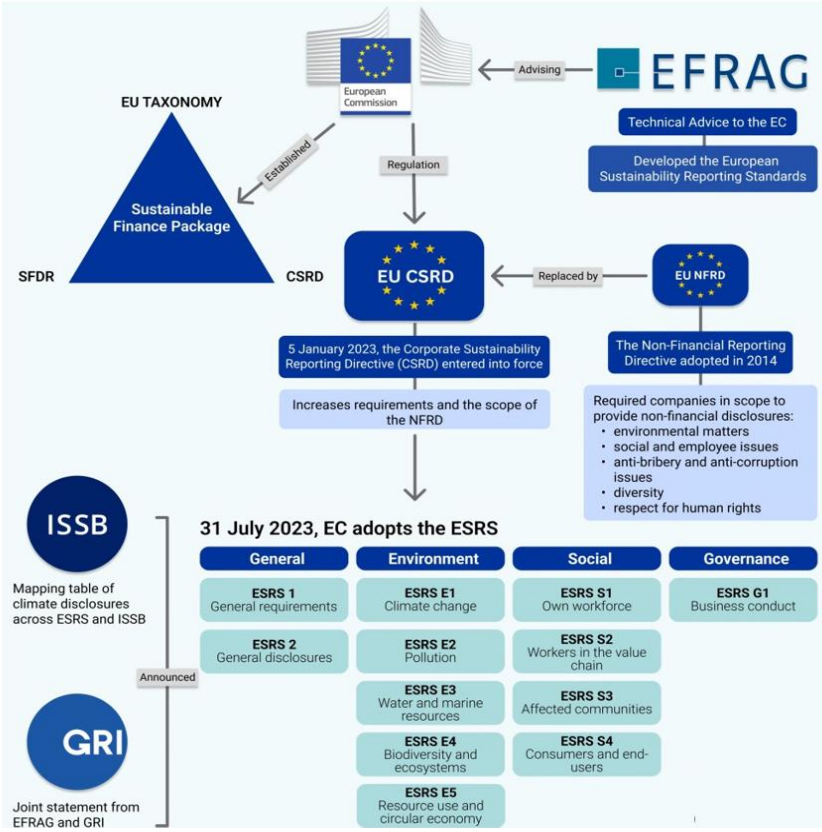


Figure 2. ESG reporting according to the CSRD

Source: https://www.efrag.org/,15/05/2025

The first wave of ESG reporting according to the ESRS started previous year - for companies (with the reporting in 2025) if they fulfill two of the three following criteria:

• € 20 million balance sheet

• € 40 million net turnover

• average number of 250+ employees

Those large and EU-listed companies have to publish their first report in 2025 for the FY 2024. The timeline below shows the CSRD implementation stages for other concerned companies:

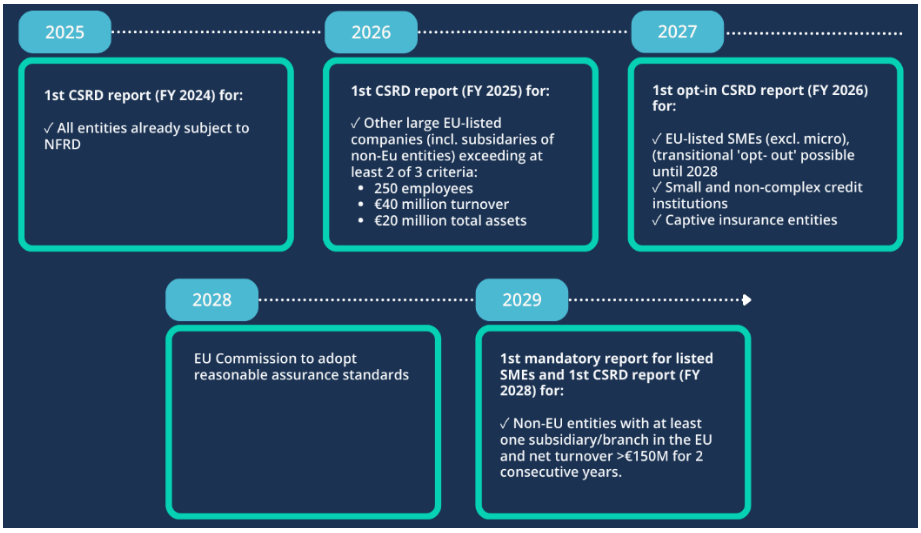


Figure 3. The CSRD implementation stages for other concerned companies

Source: https://shipzero.com/,15/05/2025

After supplementary the first simplification ESG reporting according to the CSRD (in 2024), values of criteria were increased by 15% (https://www.pwc.ch/,15/05/2025).

As part of this ESG management and reporting process, understanding and implementing a double materiality assessment (DMA) is critical - this is the most complicated process during the preparation of transparent and objective integrated report. A double materiality assessment is a process for evaluating and prioritizing sustainability topics that are relevant to a company's operations and value chain. It assesses materiality from two perspectives:

- Financial materiality: This perspective focuses on how sustainability issues impact the company's financial performance. E.g., risks such as changes in environmental regulations, resource scarcity, or shifting consumer preferences could directly affect a company's costs, revenues, or overall financial stability.
- Impact materiality: This perspective considers the broader impact a company's activities have on society and the environment. This might include a company's carbon emissions, water usage, or social contributions, such as promoting diversity and inclusion (https://www.ey.com/, 15/05/2025).

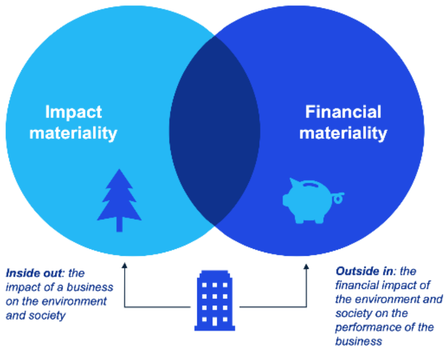


Figure 4. Double materiality dimensions

Source: https://kpmg.com/,15/05/2025

The strategic value of double materiality: Though initially rooted in corporate responsibility and regulatory compliance, the role of double materiality has evolved. Organizations now employ it as a broader business strategy and risk assessment tool. This approach allows them to:

- Integrate sustainability practices into existing business operations.
- Align their sustainability strategies with their overall business goals.
- Anticipate potential impacts on financial performance and plan for business resilience.

A foundation for effective CSRD reporting: Double materiality assessment is more than just a reporting exercise; it is a strategic process that can transform how a company views and manages sustainability. As you prepare for CSRD reporting, incorporating a robust DMA will set a solid foundation for compliance, strategy development, and long-term business success.

2 Research Design

All research activities during the whole investigation period were carried out based on the application of the three-dimensional perspective logic of the research process:

2.1 Research Aims

It is the evaluation of specific attributes of the most relevant changes generated by Omnibus directive and their related impacts, we setup these partial goals:

- To identify a current attribute of ESG management and reporting
- To define the basic meaning of the Omnibus directive
- To describe the core changes generated by Omnibus directive
- To identify their related impacts on enterprise economy and management

Figure 5. Three-Dimensional Perspective of the Research Process

Source: Self-elaboration

2.2 Object of the Research

This article takes big importance in the providing of real information with a real view on the object of this research. The central part of our research is focused on specific attributes of the Omnibus directive and its impacts.

2.3 Methodology of the Research

Considering the complexity of the problem regarding the managerial activities of the enterprise in the area of Omnibus implantation and its solutions, such a combination of methods was applied which was appropriate to accomplish the exacting goals (due to saving of space, only the outline is stated here in Figure....):

APPLICATION OF METHOD COMBINATION FOR RESEARCH PURPOSES	
General methods	**Specific methods**
A/ Logical methods	▪ meta-analysis
▪ analysis – synthesis	▪ benchmarking
▪ induction – deduction	▪ structured interview
▪ abstraction – concretization	▪ direct and indirect diagnosticities (via indicators)
▪ analogy and implication	▪ mathematical methods
B/ Empirical methods	▪ statistical methods
▪ observation	▪ graphical methods
▪ measurement	▪ simulation
▪ experiment	▪ application of information and communication technologies
Synergy (interaction)	

Figure 6. Particular Scientific Methods for the Research
Source: Self-elaboration

3. Key Result and Discussion of the Research Focused on the Omnibus Directive and its Impacts

The Omnibus directive was published in the Official Journal of the European Union on 16/04/2025 and entered into force the following day with these requirements:

SEGMENTS	STATUS QUO	OMNIBUS CHANGES
Sector-specific information	Mandatory sector-specific reporting standards	Removal of mandatory sector-specific standards
Reporting of value chain information	Companies required to obtain data from all suppliers	Cap on value chain information to avoid "trickle-down"
ESRS	Full set of ESRS (subject to materiality)	Planned revision of ESRS: fewer data points, focus on quantitative data, data points to be made voluntary
Standards for small and medium enterprises (SMEs)	– Non-official or -binding voluntary SME (VSME) standard provided by EFRAG – Listed SME standards for companies in Wave 3	– Revised VSME to be adopted as a Delegated Act; Commission to issue recommendation on voluntary reporting as soon as possible – LSME standards removed
Double materiality assessment	Required (both financial and impact materiality)	Remains required
Assurance obligations	– Limited assurance required – Plans to transition to reasonable assurance – Adoption of standards for sustainability assurance by 2026	– Limited assurance requirement remains – Reasonable assurance requirement removed – Targeted assurance guidelines to be provided by 2026, encompassing standards to follow

Figure 7. The EU Omnibus package
Source: https://kpmg.com/, 15/052025

The EU Omnibus package rolls back many previous disclosure requirements that provided transparency into a business's value chain. Member states of the EU have until 31/12/2025 to transpose this Directive into national law. The Omnibus directive delays the application of the Corporate Sustainability Reporting Directive (CSRD) for companies in the 2nd wave and the 3th wave until 2028. Since this, there have been a series of partial changes:

I. The first few member states of the EU have started the process of implementing the directive;

II. The EC has signaled its intent to provide some limited relief for companies in the 1st wave who are already required to comply with CSRD;

III. Political negotiations on the CSRD and the Corporate Sustainability Due Diligence Directive (CSDDD) have begun in earnest (https://www.efrag.org/,15/05/2025).

3.1 Omnibus Simplification Package related to the CSRD Changes

On 13/05/2025 during a meeting of the Committee on Legal Affairs of the European Parliament, a spokesperson for the European Commission confirmed that the Commission plans to adopt a "quick fix" delegated act. The delegated act would oblige companies in Line 1 to continue reporting but will implement a two-year delay for the phase-in provisions under the European Sustainability Reporting Standards (ESRS):

- for all companies in the 1st wave, the anticipated financial effects of risks and opportunities relating to climate change (E1), pollution (E2), water and marine resources (E3), biodiversity and ecosystems (E4), resource use and circular economy (E5); and certain information and datapoints relating to own workforce (employee) (S1); and
- for companies in the 1st wave or groups with 750 or fewer employees, scope 3 emissions and total GHG emissions, and information and/or datapoints (as applicable) under biodiversity (E4), own workforce (S1), value chain workers (S2), affected communities (S3) and consumers (S4).

The rationale for this "quick fix" directive is that although companies in the 1st wave may be obliged to report now, some of these companies may no longer be in scope for CSRD following the changes being proposed in the Omnibus simplification package. (https://www.hoganlovells.com/, 15/05/2025).

The Omnibus package includes simplifications in sustainability due diligence, EU Taxonomy, carbon border adjustments and investment programs. According to the EC, this should enable a cost-effective implementation of sustainability rules, reducing the administrative burden overall by about 25% and for small and medium-sized enterprises (SMEs) by about 35%:

ELEMENT	STATUS QUO OF THE CSRD	OMNIBUS CHANGES
Scope of reporting companies	First wave: All companies falling under the NFRD (Non-Financial Reporting directive) Second wave: Reporting is mandatory for large undertakings fulfilling two of three criteria: - >250 employees - >€50 million net turnover - balance sheet above €25 million Third wave: SMEs	Second wave: Reporting should be mandatory for undertakings with more than 1,000 employees and either turnover of €50 million or a balance sheet above €25 million
Postponing reporting requirements	Second wave mandatory to report in financial year 2025, third wave in 2026	Reporting requirements for both waves postponed for 2 years
European Sustainability Reporting Standards (ESRS)	Companies falling under the CSRD are required to use the ESRS	Reducing the number of data points.
Sector-specific standards	Sector-specific standards should be developed to simplify the reporting requirements	No sector-specific standards should be adopted
Assurance	Limited assurance should be extended to reasonable assurance in the future	Only limited assurance

Figure 8. CSRD Changes
Source: https://www.weforum.org/, 15/052025

3.2 Limiting the Scope and Amending the Content of the EU Taxonomy

The Commission proposes making the EU Taxonomy mandatory for only a subset of large companies – i.e. those with:

- more than 1,000 employees; and
- a net turnover of more than EUR 450 million.

In contrast, companies wanting to claim voluntarily that their activities are taxonomy-aligned would, as a minimum, need to disclose KPIs on turnover and capital expenditure.

Additionally, the EC is working to simplify the EU Taxonomy, including introducing a materiality threshold, simplifying the 'Do No Significant Harm' criteria on pollution and revising the reporting templates. These changes would apply initially in FY25 for reporting in 2026:

ELEMENT	STATUS QUO OF THE EU TAXONOMY	OMNIBUS CHANGES
Scope of reporting companies	All companies falling under the CSRD must mandatorily report according to the EU taxonomy	Companies with <1,000 employees and net turnover up to €450 million can **voluntarily** report on the Taxonomy
Partial alignment	Only fully aligned activities are considered as ecologically sustainable	Partial alignment with the Taxonomy should be possible
Materiality thresholds	Companies could set and provide reasoning for thresholds by themselves	No reporting for activities that are not financially material (e.g., not exceeding 10% of turnover, Capex or Opex)

Figure 9. EU Taxonomy Changes
Source: https://www.weforum.org/, 15/052025

3.3 Key Changes in the Corporate Sustainability Due Diligence Directive (CSDDD)

Requested changes in CSDDD:

- Timeline: Postponed by one year, with the transposition deadline moved to July 26th, 2027, and first year of application effective as of July 26th, 2028.
- Scope: Limits the information large companies can request from SME and small mid-cap business partners to that laid out in the CSRD's VSME.
- Simplification: Reduction of the frequency of assessments (from annual to every five years) and simplification of other aspects of sustainability due diligence requirements (in-depth assessment only with direct suppliers), as well as aligning the climate transition plan requirements with the CSRD.
- Civil liability: Removed the harmonized EU conditions for civil liability, which has been left for national law to define:

ELEMENT	STATUS QUO OF CCDDD	OMNIBUS CHANGES
Postponing reporting requirements	Companies of Group 1 should report for 2027	The reporting requirements should be postponed by one year. Until then, guidelines should help the companies to build on best practices
Value chain coverage	Covers direct and indirect suppliers	Focus on direct business partners (Tier 1)
Monitoring	Yearly monitoring	Prolonging the intervals of assessments from one to five years
Harmonization	Member states allowed to adopt stricter rules	National rules must not deviate from European law

Figure 10. CCDDD Changes
Source: https://www.weforum.org/, 15/052025

3.4. Carbon Border Adjustment Mechanism (CBAM)

- Scope: The new cumulative annual threshold of 50 tons maximum (corresponding to approximately 80 tons of CO2 eq.) will exempt 90% of importers from CBAM.
- Simplification: Emission calculations and reporting requirements have been simplified.
- Measures strengthening anti-abuse provisions and anti-circumvention strategies with national authorities have been introduced (https://www.efrag.org/,15/05/2025).

3.5 How can companies prepare for the changes?

With the release of the Commission's first Omnibus package, now is a good time for companies to identify any 'no-regret moves' that they can focus on, such as:

- revisiting CSRD scoping to understand how the proposed thresholds might influence reporting;
- reprioritizing efforts and focusing on strategic actions that go beyond compliance, for example:
    - transition planning;
    - materiality assessment; and
    - a focus on the data that is relied on for strategic decision making.
- continuing dialogue with stakeholders around policies, actions and targets across material topics and clarifying sustainability-related messaging; and
- with reporting under IFRS® Sustainability Disclosure Standards from the ISSB5 on the horizon in various major jurisdictions outside the EU, considering moving forward on climate, particularly preparing Scope 1, 2 and 3 greenhouse gas emissions inventory and identifying and mitigating climate-related risks (https://kpmg.com/, 15/05/2025).

4. Conclusion

As regulatory requirements continue to evolve, companies should remain proactive in adapting to the shifting sustainability landscape. The Omnibus proposals mark a step toward streamlining corporate due diligence, but they also signal ongoing adjustments that will help shape future compliance obligations. Businesses should take a forward-thinking approach, strengthening governance, refining monitoring systems and preparing for potential revisions. By staying ahead of these developments, companies can build resilience, maintain compliance and position themselves as leaders in sustainable and responsible business practices.

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Gender Equality and Innovation in Slovak Organizations: Insights from Survey Data and a Bibliometric Analysis

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Abstract: This study presents a bibliometric analysis of academic literature on gender equality and innovation in Slovak organizations. Based on 11 publications indexed in the Web of Science (2014–2023), the analysis maps publication trends, citation metrics, and key research themes using Biblioshiny. Although the number of publications remains low, the citation performance is notable, with an average of 11.27 citations per document and an H-index of 5. Core topics include gender diversity in leadership, women in STEM, inclusive innovation policies, and institutional barriers. Highly cited works explore the influence of ESG practices and social capital on innovation outcomes. While research in the Slovak context is still limited, the findings indicate growing recognition of gender diversity as a strategic innovation factor. The study highlights gaps such as the lack of intersectional and longitudinal research and calls for stronger interdisciplinary collaboration to support inclusive innovation ecosystems.

Keywords: gender equality; inclusive innovation; Slovakia; women in STEM; diversity in research

Introduction

Gender equality has increasingly become a central element in discussions on organizational innovation, particularly as inclusive practices are now recognized as drivers of creativity, adaptability, and long-term sustainability. Within the European Union, including Slovakia, the strategic promotion of gender equality is not only a matter of social justice but also an economic imperative aligned with innovation and growth objectives outlined in key policy frameworks such as Horizon Europe and the European Innovation Agenda (European Commission, 2020; 2022).

Research suggests that diverse teams, especially those with gender-balanced representation, are more likely to develop novel ideas, challenge groupthink, and address societal needs with broader perspectives. Østergaard, Timmermans, and Kristinsson (2011) found a positive relationship between gender diversity and innovation performance in Danish firms, while Díaz-García, González-Moreno, and Sáez-Martínez (2013) confirmed similar findings across Spanish enterprises. These results align with the theoretical view that cognitive and experiential diversity enhances problem-solving and knowledge recombination in innovative processes.

Recent academic literature further supports the notion that gender equality contributes positively to both innovation performance and organizational resilience. Terjesen et al. (2016) emphasize the role of women in corporate governance and innovation strategy, while Dezső and Ross (2012) highlight the added value of female representation in top management teams, particularly in knowledge-intensive industries. These studies underline that gender-inclusive leadership is not only ethically relevant but also functionally effective in stimulating innovative output.

However, most of these studies have been conducted in international contexts, often neglecting smaller innovation ecosystems such as Slovakia. There remains a lack of empirical research focusing on how gender dynamics affect innovation within the specific sociocultural and institutional landscape of Slovak organizations. This represents a significant gap in literature and justifies the need for nationally grounded research.

This paper aims to fill that gap by presenting a survey-based analysis of gender equality and innovation practices across various Slovak firms and institutions. The study explores the relationship between gender representation, inclusive innovation strategies, and organizational performance. It also identifies key perceptions, challenges, and best practices in implementing gender-inclusive innovation frameworks.

By examining survey data from Slovak organizations, this research seeks to answer the following questions:

1. How has academic interest in gender equality and innovation in the Slovak context developed over time, and what does the current research landscape reveal?
2. What are the dominant research themes and theoretical frameworks addressing gender diversity in innovation-related **scholarships**?
3. Which academic contributions have had the greatest influence on shaping the discourse around gender-inclusive innovation in Slovakia?

This study contributes to both the academic and policy-oriented discourse by providing empirical evidence from a national context that is often underrepresented in international gender and innovation research. In doing so, it lays the groundwork for more targeted policy recommendations and organizational reforms that foster gender-inclusive innovation ecosystems in Slovakia.1. Literature Review

In the literature review the current state of the research field should be carefully reviewed and key publications cited. Please highlight controversial and diverging hypotheses when necessary. Finally, briefly mention the main aim of the work and highlight the principal conclusions. As far as possible, please keep the theoretical background comprehensible to scientists outside your field of research. References should be cited with author and year of publication.

2. Methodology

This study conducts a bibliometric analysis of research on gender equality and innovation within the Slovak context, focusing on the role of inclusive practices, women's representation in STEM, and diversity-driven strategies in enhancing innovation performance. The analysis examines publication trends from the Web of Science database to identify research gaps, dominant themes, and emerging patterns in academic discourse. The primary goal is to understand how gender equality is addressed in innovation-related literature and to assess the academic impact and collaboration dynamics within this field.

Building on the established methodology and the refined dataset, the following section presents the analytical steps applied in this bibliometric study. The analysis defines specific research objectives and scope, emphasizing gender inclusion, organizational innovation, and diversity in Slovak R&D and corporate sectors. Data were collected from the Web of Science database using the following keywords: "gender equality", "Slovakia", "inclusive innovation", "women in STEM", and "diversity in research". The selected dataset, exported in BibTeX format, was analyzed using Biblioshiny (an R-based bibliometric analysis tool) to evaluate publication volume, author collaboration networks, keyword co-occurrence, and thematic structures.

To provide greater transparency, the steps involved in the dataset selection and refinement process are visually summarized in Table 1.

Table 1. Steps in the Literature Review Process for Gender Equality and Innovation Research

Step	Details
Step 1: Criteria for reviewing existing literature (inclusion and exclusion)	Classification: Peer-reviewed journal articles and proceedings focused on gender equality, innovation, inclusive leadership, and diversity in Slovak research or organizations. Exclusion: Dissertations, book chapters, editorials, and documents lacking innovation context.
Step 2: Literary research	Database: Web of Science Core Collection Terms used: "gender equality", "Slovakia", "inclusive innovation", "women in STEM", "diversity in research"

Step 3: Refine the selection of literature studies	Analysis: Excluded papers that were not directly relevant to gender and innovation or lacked Slovak focus. Final sample: 11 documents
Step 4: Reducing the scope of the study sample	Further refinement excluded theoretical-only works without measurable empirical relevance. Final dataset: 11 documents (10 articles, 1 proceedings paper)
Step 5: Analysis of selected articles	Articles were systematically analyzed using bibliometric methods with focus on: - Publication trends - Citation metrics (H-index = 5; 124 citations) - Keyword mapping - Co-authorship and collaboration networks
Step 6: Presentation of findings	The findings revealed limited research activity but growing academic attention to inclusive innovation, gender in R&D, and institutional barriers. Key themes include women's roles in STEM, innovation leadership, and diversity in Slovak innovation ecosystems.

Source: own proceedings by Senyo et al. (2019)

3. Bibliometric analysis results

This study provides a bibliometric analysis of academic publications on gender equality and innovation in the Slovak context, covering the period from 2014 to 2023. As shown in Table 2, the dataset comprises 11 distinct documents obtained from the Web of Science database. These include 10 journal articles and 1 proceedings paper, reflecting focused academic engagement with the topic. The annual growth rate of publications in this field is 0%, indicating no increase in publication volume across the studied period. Despite this, the average age of documents is 5.09 years, which suggests recent and still relevant scholarly contributions. The dataset has an average of 11.27 citations per document, confirming steady academic attention and interest in gender equality and inclusive innovation themes in Slovakia.

In terms of content, the analysis reveals 49 Keywords Plus entries and 56 Author Keywords, pointing to a consistent but specialized terminology. Dominant research themes include gender equality, inclusive innovation, women in STEM, and diversity in research, underlining the interdisciplinary nature of the subject and its connection to social, educational, and technological dimensions. Although the dataset is limited in size, the structured metadata confirms it is sufficiently robust for analyzing emerging research trends, authorship patterns, and terminological focus areas relevant to gender-inclusive innovation in Slovak organizations.

Table 2. Summary information of the dataset

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2014:2023
Sources (Journals, Books, etc)	11
Documents	11
Annual Growth Rate %	0
Document Average Age	5.09
Average citations per doc	11.27
References	624
DOCUMENT CONTENTS	
Keywords Plus (ID)	49
Author's Keywords (DE)	56
AUTHORS	
Authors	28
Authors of single-authored docs	2
AUTHORS COLLABORATION	
Single-authored docs	2
Co-Authors per Doc	2.91
International co-authorships %	36.36
DOCUMENT TYPES	
article	10
proceedings paper	1

Source: own proceedings in Biblioshiny

The dataset comprises 11 academic publications indexed in the Web of Science database, covering the period from 2014 to 2023. These documents have been cited 124 times in total, with 123 citations excluding self-citations, reflecting a moderate yet focused academic impact. The average number of citations per document is 11.27, indicating stable scholarly engagement within this niche field.

Figure 1. Summary of Dataset Statistics and H-Index

Source: Web of Science

The dataset has an H-index of 5, which means that five documents were cited at least five times, demonstrating that a core group of articles has achieved notable visibility in the academic community. A total of 119 citing articles were identified, with 118 of them excluding self-citations, highlighting the external recognition of the selected publications. These metrics underscore the emerging relevance of gender equality and innovation as interconnected research areas, particularly in the Slovak context, and suggest growing academic interest in inclusive innovation policies and gender-sensitive research frameworks.

3. 1 Thematic Structure of the Field: Word Cloud Analysis

The Word Cloud presented in Figure 2 offers a visual representation of the most frequent keywords used across the selected publications in the domain of gender equality and innovation in Slovakia. The figure was generated through Biblioshiny and highlights core terminologies that define the research landscape.

Among the most dominant terms are "performance," "diversity," "companies," "corporate governance," and "panel-data"—suggesting a strong orientation of the field toward exploring the impact of gender diversity on organizational effectiveness and governance structures. The emphasis on "diversity" and "performance" reflects a recurring interest in how inclusive innovation practices and gender balance contribute to improved decision-making, innovation outcomes, and resource allocation.

Other notable keywords such as "impact," "accruals," "employees," and "earnings management" imply a strong connection to corporate performance metrics, where gender equality is examined through quantifiable outputs. The presence of terms like "self-esteem," "women," "ethnic," "tolerance," and "culture" also indicates that psychosocial, behavioral, and cultural factors are increasingly incorporated into the research framework.

The inclusion of "contextual variables," "adoption," "transition," "board composition," and "employment" further supports the notion that innovation and inclusion are influenced by governance mechanisms and labor dynamics, echoing findings from prior bibliometric studies on gender diversity (e.g., Maddi & Gingras, 2021; Ferrary & Déo, 2023).

While the dominant cluster of terms focuses on measurable outcomes and firm-level analysis, the appearance of terms like "sustainability," "pro-poor," and "life satisfaction" suggests a secondary focus on social equity and broader societal impacts of inclusive practices—consistent with strategic innovation policy goals in the European context.

Figure 2. Word Cloud of Most Frequent Keywords in the Dataset,

Source: Own proceedings in Biblioshiny

This keyword landscape indicates that research on gender equality and innovation in Slovakia is still largely concentrated on performance-driven and corporate governance outcomes, with growing attention toward inclusive strategies and cultural aspects. However, there appears to be an underrepresentation of policy-level and institutional analysis, which opens new avenues for future research—particularly in the Slovak context where empirical studies remain limited.

Thematic Structure of the Field: Word Cloud Analysis

3.2 Analysis of Author's local impact

The local academic impact of authors contributing to the field of gender equality and innovation in the Slovak context is presented in Table 3 and visualized in Figure 2. This analysis was conducted using Biblioshiny, based on a curated dataset of 11 documents retrieved from the Web of Science. Despite the relatively small volume of publications, several authors demonstrate a notable degree of scholarly engagement and influence within this emerging area of research.

Among the leading contributors, Durana P. and Valaskova K. stand out with the highest H-index of 3, indicating that each of them has authored at least three publications cited three or more times. Both authors have also accumulated a total of 72 citations, reflecting sustained academic activity and consistent relevance within the thematic scope of inclusive innovation and gender diversity.

Other prominent contributors include Alexy M., Belas J., and Elvira E., each of whom authored a single publication that garnered 49 citations. Their high citation count despite limited publication volume underscores the significant academic visibility that individual contributions can achieve in this niche research domain. In addition, authors such as Babelova Z.G., Bacova V., Blazek R., Boda M., and Chlpeková A. also appear in the dataset, each with one publication and an H-index of 1, suggesting emerging scholarly engagement in the intersection of gender, innovation, and organizational studies.

These findings reveal a diverse mix of established researchers and early-stage contributors who are shaping the academic discourse on gender equality and innovation in Slovakia. While the overall volume of literature is modest, the citation performance indicates a growing academic interest and relevance of the topic within the national research community.

Table 3: Authors' Local Impact

Author	H-Index	G-Index	M-Index	TC	NP	PY_start
DURANA P	3	3	0.500	72	3	2020
VALASKOVA K	3	3	0.500	72	3	2020
ALEXY M	1	1	0.143	49	1	2019

Author	H-Index	G-Index	M-Index	TC	NP	PY_start
BELAS J	1	1	0.200	49	1	2021
ELVIRA E	1	1	0.200	49	1	2021
BABELOVA ZG	1	1	0.200	9	1	2021
BACOVA V	1	1	0.143	9	1	2019
BLAZEK R	1	1	0.167	7	1	2021
BODA M	1	1	0.200	9	1	2021
CHLPEKOVÁ A	1	1	0.200	9	1	2021

Source: Own proceedings using Biblioshiny

After analyzing authors, we identified the most influential publications based on citation frequency. Table 4 summarizes the top ten publications in gender balance research, ranked by total global citations (TC) and citations per year (TC/Y).

Table 4: Most relevant publications in the field

Title of publication	Journal	Year	Total citation	Total Citations per Year
Equality and Performance in Corporate Governance (Kliestik et al.)	Ekonomska Istraživanja	2021	49	9.80
Gender Inequality, Social Capital, and Innovation in Slovakia (Michalek)	Social Indicators Research	2019	32	4.57
Inclusive Innovation and Sustainable Leadership (Durana)	Journal of Business Economics and Management	2022	16	4.00
Barriers to Gender-Inclusive Innovation in Public Institutions (Vranakova)	Sustainability	2021	9	1.80
Risk Preferences, Gender, and Financial Literacy (Blazek)	Journal of Risk and Financial Management	2020	7	1.17
Gender Balance and Market Competitiveness in Slovak Regions (Soltes)	Equilibrium	2023	4	1.33

Title of publication	Journal	Year	Total citation	Total Citations per Year
Institutional Frameworks and Gender Equality: Slovak Perspective (Ochotnicky)	Acta Oeconomica	2019	3	0.43
Measuring Diversity in Operations Research Teams (Boda)	RAIRO - Operations Research	2021	3	0.60
Gender Identity and Psychological Capital in Research Institutions (Bacova)	Československá Psychologie	2019	1	0.14
Organizational Culture and Gender Inclusion (Malicka)	Ekonomický časopis	2020	0	0.00

Source: Own proceedings based on Biblioshiny

1. (KLIESTIK ET AL., 2021) TC = 49, TC/Y = 9.80 The authors investigate the relationship between ESG (Environmental, Social, and Governance) practices and corporate performance, focusing on the role of voluntary non-financial disclosures. Based on data from Central European firms, the findings indicate that companies implementing ESG strategies tend to achieve stronger profitability and market valuation. This supports the argument that sustainability, transparency, and ethical conduct are positively linked to long-term business success and stakeholder confidence.
2. (MICHALEK, 2019) TC = 32, TC/Y = 4.57 Michalek explores how social capital dimensions—such as trust, inclusion, and civic participation—affect innovation in Slovakia. Gender equality is assessed as a key variable influencing innovation ecosystems. The study uses regional data to demonstrate that societies with higher gender parity perform better in innovation outputs. The paper contributes to innovation policy debates by advocating for social and gender inclusiveness as a core part of regional development strategies.
3. (DURANA, 2022) TC = 16, TC/Y = 4.00 Durana's paper assesses the influence of ESG disclosure on company performance using regression models applied to a European firm dataset. The results confirm a positive relationship between sustainability transparency and financial returns. The study argues that ethical and environmentally conscious management practices are increasingly rewarded by markets and stakeholders. It underscores ESG as not just reputational, but financially strategic.
4. (VRANAKOVA, 2021) TC = 9, TC/Y = 1.80 This article identifies institutional and cultural barriers that hinder the integration of gender-inclusive practices in Slovak public innovation systems. Vranakova proposes participatory innovation policies and increased support for women in STEM to close the gender gap. The work highlights the lack of intersectionality in public innovation efforts and calls for systemic reforms to foster inclusivity in decision-making and research funding structures.
5. (BLAZEK, 2020) TC = 7, TC/Y = 1.17 Blazek's study focuses on how gender differences in risk aversion and financial literacy influence investment behavior. Using empirical data from financial literacy surveys, the findings suggest that women tend to be more cautious in financial decisions. The paper calls for improved financial education and tailored investment support for women to close knowledge gaps and enhance financial inclusion.
6. (SOLTES, 2023) TC = 4, TC/Y = 1.33 Soltes evaluates the impact of gender equality on regional competitiveness in Slovakia. Through a regional benchmarking framework, the paper shows that areas with greater gender parity demonstrate stronger labor market performance and innovation

potential. The study argues for integrating gender-sensitive indicators into regional development and innovation policy to maximize socioeconomic growth.

7. (OCHOTNICKY, 2019) TC = 3, TC/Y = 0.43 Ochotnicky reviews Slovak policy initiatives that support gender equality, focusing on institutional design, legal mechanisms, and the role of European Union frameworks. While policies are in place, the study finds limited implementation and effectiveness due to persistent cultural barriers. The paper proposes more rigorous performance metrics and accountability systems in gender policy enforcement.
8. (BODA, 2021) TC = 3, TC/Y = 0.60 This article explores the impact of diversity—gender, age, and ethnicity—on operational research team performance. Through model simulations and productivity assessments, the findings indicate that diverse teams achieve higher creativity and better outcomes in problem-solving. Boda supports the need for diversity-focused hiring in research and academic settings to improve interdisciplinary collaboration.
9. (BACOVA, 2019) TC = 1, TC/Y = 0.14 Bacova investigates psychological capital among researchers in Slovak academic institutions, particularly focusing on gender identity and workplace inclusion. The study finds that inclusive organizational climates improve employee well-being and resilience. It advocates for gender-sensitive HR policies in education and research sectors to foster engagement and productivity.
10. (MALICKA, 2020) TC = 0, TC/Y = 0.00 Malicka explores the influence of organizational culture on gender inclusion in Slovak businesses. Based on interviews and qualitative coding, the study identifies key cultural barriers—such as hierarchy and stereotypes—that inhibit diversity. It suggests leadership development and cultural audits as tools to build more inclusive corporate environments.

4. Discussion

This research paper conducted a bibliometric analysis of 11 academic publications indexed in the Web of Science database between 2014 and 2023, focused on the intersection of gender equality and innovation in Slovak organizations. Using the Biblioshiny software, the analysis highlighted the scope, impact, and emerging themes within this niche but increasingly relevant academic field. Below, we address the initially formulated research questions.

1. How has academic discourse on gender equality and innovation evolved in recent years?

The bibliometric findings suggest that although the volume of Slovak-based research on gender-inclusive innovation is limited, it is gaining growing recognition in terms of citations and thematic relevance. Despite a 0% annual growth rate in document output, the average citation count per document (11.27) and an H-index of 5 indicate strong academic resonance. From 2014 onward, publications began to address the role of gender in STEM, inclusive leadership, and innovation policy. This marks a shift toward broader acknowledgment of diversity as a key driver of innovation capacity and systemic resilience.

2. What are the primary research themes and theoretical approaches in the field?

The primary research themes identified in the field include the role of gender diversity in innovation teams and leadership structures, the persistent underrepresentation of women in STEM fields, the development and implementation of inclusive innovation policy frameworks, and the psychological and institutional barriers that hinder gender equality in organizational contexts. These topics reflect an ongoing effort to understand how diversity contributes to innovation dynamics and organizational performance. The theoretical approaches applied across the literature primarily draw on institutional theory, resource-based views, and social capital theory. These frameworks collectively emphasize the strategic value of diversity in facilitating knowledge recombination, enhancing team effectiveness, and driving sustainable innovation outcomes.

3. Which publications demonstrate the greatest academic impact?

The bibliometric analysis identified several influential publications that have shaped scholarly discourse on gender equality and innovation in the Slovak context. Among them, the most cited work is by Kliestik et al. (2021), with 49 total citations and an average of 9.80 citations per year. This study explores ESG strategies and the integration of gender equality within corporate governance frameworks, offering valuable insights into how diversity supports sustainable organizational performance. Another key contribution comes from Michalek (2019), whose work on social capital and gender equity in innovation received 32 citations (TC/Y = 4.57), emphasizing the importance of inclusive social structures in driving regional innovation capacity. Durana (2022) also features prominently, with 16 citations (TC/Y = 4.00), highlighting the role of inclusive leadership and transparent ESG reporting in enhancing firm performance. Additionally, research by Vranakova (2021) and Blazek (2020) provides nuanced perspectives on institutional gender inclusion and behavioral differences in financial decision-making, respectively—reinforcing the multidimensional nature of gender-focused innovation research.

5. Conclusion

These findings indicate that, despite the limited volume of publications in the Slovak context, certain authors and topics have gained meaningful academic visibility. The intersection of governance, diversity, and innovation appears to be a particularly influential area. Nevertheless, the current literature still lacks comprehensive intersectional approaches, comparative studies across regions and time, and empirical assessments of long-term outcomes. Future research should address these gaps by investigating how gender-inclusive strategies impact organizational resilience and innovation in various institutional environments. Overall, the academic impact of these selected works supports the growing recognition of gender equality not just as a social imperative, but as a core element of innovation policy and practice. Organizations and institutions that prioritize inclusive leadership are likely to be more adaptive, competitive, and aligned with sustainable development goals in an increasingly complex global landscape.

Practical Implications

This study emphasizes that integrating gender diversity into leadership structures is crucial not only for ethical and social reasons but also for enhancing organizational performance. Policymakers are encouraged to go beyond regulatory quotas by creating supportive environments that foster women's advancement into leadership roles. Corporate leaders should implement comprehensive diversity strategies, including mentorship programs, transparent promotion policies, and inclusive workplace cultures, recognizing that gender diversity contributes directly to innovation, strategic adaptability, and improved risk management. In addition, organizations should systematically monitor and publicly report progress on gender diversity indicators as part of their sustainability and governance disclosures. Leadership development programs should be tailored specifically to prepare women and other underrepresented groups for strategic leadership roles. Policymakers are advised to design financial incentives and educational initiatives that promote inclusive leadership at all organizational levels.

Recommendations for Future Practice

Businesses should systematically embed diversity and inclusion into their corporate strategies and sustainability frameworks. Proactively promoting gender equality can lead to greater stakeholder engagement, stronger reputational capital, and a more sustainable competitive advantage. Policymakers, on the other hand, should support these efforts through incentives, awareness campaigns, and education initiatives that highlight the broader economic and societal benefits of inclusive leadership. In conclusion, promoting gender equality in leadership is no longer optional but a strategic imperative for organizations aiming to thrive in an increasingly dynamic and socially conscious global economy. Fostering inclusive leadership will be essential for building resilient, responsible, and future-ready organizations.

Research Limitations

While this study offers valuable insights into the intersection of gender equality and innovation in Slovakia, several limitations must be acknowledged. The analysis is based on a relatively small sample of 11 publications indexed in the Web of Science, which may not fully represent the breadth of relevant research conducted in other databases, languages, or formats. Moreover, the exclusive use of bibliometric tools such as Biblioshiny, though effective for identifying patterns and trends, does not allow for in-depth content analysis or evaluation of theoretical depth. The study's timeframe, limited to 2014–2023, may also overlook very recent developments in the field. Additionally, the focus on Slovakia-specific keywords may have excluded comparative regional or international studies with applicable findings. Future research should address these limitations by incorporating mixed-method approaches, expanding data sources, and applying context-sensitive analysis to capture the full complexity of gender-inclusive innovation.

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New rules related to product sustainability

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Abstract: Product sustainability is a concept focused on reducing the negative environmental impact of products throughout their entire life cycle – from design and manufacturing, through distribution and use, to disposal or recycling. The goal is to create products that are environmentally friendly, economically viable, and socially fair. Product sustainability is crucial for the future of the planet, the economy, and society. At a time when we are facing climate change, the depletion of natural resources, and a growing amount of waste, it is essential to reconsider how products are made, used, and disposed of. The main objective of this article is to introduce the issue and principles of product sustainability. It also provides an overview of available sustainability tools, new legislative rules, and requirements related to ecodesign.

Keywords: Sustainability; Tools; Ecodesign

Introduction

Sustainability is increasingly coming to the forefront of many strategic objectives and support measures within the EU. It is becoming an important aspect in the decision-making process across almost all areas. It takes into account the well-being not only of the current generation but, above all, the needs of future generations. It involves responsibility and the protection of resources with a view toward the future. This requires accountability not only at the level of national governments but also openness, acceptance, and implementation by individuals.

The EU's goal is to create a climate-neutral circular economy, focused on the reuse and recycling of resources. Its ambition is to build a consumption model that contributes to a better quality of life, while minimizing environmental impact and considering the needs of future generations.

1. Literature Review

Product sustainability refers to the ability of products to be designed, manufactured, and used in a way that minimizes negative impacts on the environment, society, and the economy throughout their entire life cycle. It takes into account aspects such as efficient resource use, long lifespan, reparability, recyclability, and a low environmental footprint. (EK, 2024)

Sustainability must be viewed from multiple perspectives, as it needs to be upheld not only by producers but also by end consumers. For producers, this involves **sustainable production,** defined as: "*Economically efficient production by companies and organizations, with respect for the environment and human health, which minimizes the consumption of natural resources, energy, and hazardous substances, prevents waste generation, and at the same time ensures the production of high-quality products*." (SAŽP, 2018)

From the consumer's perspective, it is about **sustainable consumption,** which refers to: "*All everyday consumer products that we buy and use have an impact on the environment throughout their entire life cycle. This includes the raw materials used in production, the energy required for processing and later use, as well as the waste generated during the use of products or after the end of their lifespan*." (SAŽP, 2018)

Sustainable consumption involves using products and services in a way that minimizes negative impacts on the environment. It primarily concerns our lifestyle, purchasing habits, and the way we use and dispose of products and services. (Kopaničová, J. - Klepochová, D., 2013)

From a more comprehensive perspective, sustainable production and consumption define an approach that allows the use of natural resources while simultaneously reducing significant environmental impacts. The priority is to prefer and use products that contribute as little as possible to environmental degradation. At the same time, it is essential to meet basic human needs in the required quantity and quality, in order to maintain or ideally improve living conditions and preserve them for future generations. (SAŽP, 2018)

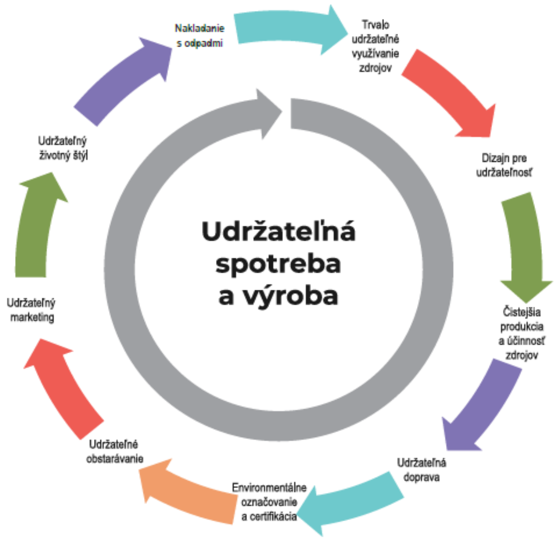

Figure 1. Sustainable Consumption and Production

Source: processed according to SAŽP (2018)

The principles and significance of product sustainability lie in:

- **Environmental protection:** Sustainable products help reduce ecological impact by minimizing the consumption of raw materials, energy, and harmful emissions. This also reduces the amount of waste that ends up in landfills or oceans.
- **Responsible consumption and production:** Sustainability promotes efficient use of resources and encourages both manufacturers and consumers to act more responsibly. This includes choosing high-quality, repairable, and recyclable products over cheap, short-lived alternatives.
- **Long-term economic benefits**: While sustainable products are often more expensive initially, their longer lifespan and lower operational costs can ultimately lead to savings. Furthermore, companies that invest in sustainability are often more competitive and attractive to customers and investors.
- **Support for health and quality of life:** Products made without toxic substances, from natural or recycled materials, are safer for people and ecosystems. Sustainable practices also contribute to better working conditions and a fairer distribution of resources.
- **Response to global challenges:** Sustainable products are a response to challenges such as the climate crisis, biodiversity loss, planet pollution, and social inequality. They contribute to achieving the Sustainable Development Goals (SDGs) set by the United Nations.

2. Methodology

The main goal of the article is to introduce the issue and principles of product sustainability. It also includes an overview of available sustainability tools, new regulations, and requirements related to ecodesign.

The subject of the study is the new requirements for sustainable products, legislative changes, and the new rules associated with them.

In the context of the scientific contribution, general research methods were used.

3. Results

In the following section, the most important tools for supporting product sustainability, the current legislation related to it, and the new rules concerning ecodesign are explained.

3.1 Tools Supporting Sustainable Production and Consumption

In terms of supporting sustainable production and consumption, several tools have been introduced, which are clearly summarized in the following Table 1:

Table 1. Tools Supporting Sustainable Production and Consumption

IMPROVING THE ENVIRONMENTAL SUSTAINABILITY OF PRODUCTS SO THAT SUSTAINABLE PRODUCTS BECOME THE NORM.	
I. SUPPORT TOOLS FOR SUSTAINABLE PRODUCTION	
ENVIRONMENTAL MANAGEMENT SYSTEM	▪ Systematic approach to solving environmental issues and continuous improvement of organizational behavior according to the ISO 14001 standard and the EMAS scheme
EMAS – SCHEME FOR ENVIRONMENTAL MANAGEMENT AND AUDIT	▪ It is an environmental management tool that goes beyond the requirements of the ISO 14001 standard with unique elements such as: ○ compliance with legal regulations under state supervision ○ direct commitment to continuously improving environmental behavior ○ transparency through mandatory communication in the form of environmental statements ○ employee participation and commitment to continuous improvement.
VERIFICATION OF ENVIRONMENTAL TECHNOLOGIES	▪ The program supports the market introduction and sale of the latest environmental technologies through independent assessment and a Technology Verification Statement. ▪ The consumer or user of the verified technology can be confident that the technology meets all declared environmental characteristics.
LIFE CYCLE ASSESSMENT (LCA)	▪ Assessment of the environmental impact of products according to the ISO 14040 series standards throughout the entire life cycle, i.e. from raw material extraction, processing, production, distribution, use, repair and maintenance, to disposal, recycling, or waste management.
BEST AVAILABLE TECHNIQUES (BAT)	▪ Best Available Technique (BAT) is the most effective and advanced state of technology and its operation method, used to demonstrate the suitability of a given technique, particularly for determining emission limits and preventing the occurrence of emissions during operation, and if not possible, at least to reduce emissions and environmental impact.
CLEANER PRODUCTION	▪ An integrated preventive environmental protection strategy focused on processes and products. Its aim is to increase production efficiency and reduce risks, not only in relation to people but also to the environment. Based on the flow of materials and energy, it identifies opportunities for better utilization, which leads to a reduction in waste and emissions and subsequently increases efficiency and competitiveness.
II. SUPPORT TOOLS FOR SUSTAINABLE CONSUMPTION	
ECODESIGN	▪ The process of product development or design, during which significant environmental impacts of production as well as the environmental properties of the finished product are identified. The goal is to design a product that will have a reduced negative impact on the environment throughout its entire life cycle. This includes lower consumption of hazardous substances, overall material and energy consumption, the possibility of ensuring easy replacement of faulty components or overall repair.
GREEN PUBLIC PROCUREMENT (GPP)	▪ A concept of public procurement that takes into account the environmental added value of products, directly contributing to environmental protection while also supporting the market for eco-friendly products and technologies.
ENVIRONMENTAL LABELING	▪ An informational tool that allows consumers to recognize which products meet stringent environmental requirements, have a lower negative impact on the environment, and are more health-conscious for the consumer. ▪ In Slovakia, environmental labeling is carried out through the national scheme for awarding the national environmental label "Environmentally

	Suitable Product" (EVP) and the European scheme for awarding the European label "EU Ecolabel."
ENERGY LABELING	▪ It is the labeling of products with the appropriate label. Products that are placed on the market or put into operation and have an impact on energy consumption during use are labeled.

Source: processed according to SAŽP (2018)

3.2 Legislation Related to Product Sustainability

Currently, one of the main objectives of the European Union is sustainable growth. In response to the rapidly changing climate and the increasing demand for energy and resources, the EU has introduced several policies and initiatives aimed at sustainable production and consumption. Based on the European Green Deal and the Circular Economy Action Plan, a legislative initiative for sustainable product policy has been adopted, with the goal of preparing products for a climate-neutral circular economy and efficient resource use. (EÚ, 2024)

At the same time, the aim of the new European rules is to support and enhance the repair culture, ensure that products are environmentally friendly, and prevent misleading advertising to consumers. The EU has already initiated several steps and measures to implement and realize the so-called consumption model. Among the most significant are:

- **Directive on the Right to Repair** (adopted in April 2024) **–** introduces rules that aim to make repairs simple and accessible. Consumers should be better informed about repairs, which should encourage them to repair products instead of replacing them. Retailers should also prioritize repair if it is cheaper or equally costly as replacing the product. The goal of the directive is to support sustainable consumption by making it easier to repair faulty products, reducing waste, and promoting the repair sector. It is an important step in the implementation of the circular economy.
  (Európsky parlament, 2024)
- **Regulation on Ecodesign** (adopted in April 2024) **–** aims to ensure that environmental aspects are considered during the product design phase. It expands the scope of products it applies to and introduces additional requirements and minimum standards for durability, reparability, energy efficiency, and recyclability. It will also address issues of premature obsolescence to prevent the loss of product functionality due to design features, the unavailability of spare parts, or insufficient software updates. Ecodesign requirements should primarily apply to products with a significant environmental impact, including iron, steel, aluminum, textiles, furniture, tires, cleaning products, paints, and chemicals. The regulation also aims to stop the destruction of unsold products, which represents the wasting of valuable economic resources and is becoming an environmental problem. For large companies, the regulation imposes the obligation to report the number of unsold and destroyed products, along with the justification for their disposal. The disposal of unsold clothing, accessories, and footwear will be banned two years after the regulation comes into effect and will later be extended to other categories. Products must have a digital passport providing consumers with relevant information to make informed decisions. (See more in section 3.3) (Európsky parlament, 2024)
- **Directive on Environmental Claims –** complements the EU ban on greenwashing and introduces a verification system for companies that want to make environmental claims. Companies must substantiate their claims and obtain preliminary approval from verifiers designated by EU countries. The aim is to ensure that all information about the product's environmental impact, its lifespan, reparability, composition, production, and use is supported by verifiable sources. Consumers should be fully informed about the warranty period of products. The goal of the directive is to introduce new rules for more responsible advertising to stop unfair greenwashing practices, where companies create the impression that a product is more environmentally friendly than it actually is.
- **Directive on Batteries** – its aim is to ensure that batteries can be reused, regenerated, or recycled after the end of their lifecycle. Batteries should thus become more sustainable, efficient, and durable. They will need to have a label indicating their carbon footprint, making the environmental impact more transparent. This requirement will apply to electric vehicle (EV)

batteries, light mobility vehicle (LMV) batteries, and rechargeable batteries with a capacity of over 2 kWh. This information will cover the entire battery lifecycle, with a guarantee of a minimum level of recycled materials in new batteries. Batteries should be easier to remove and replace – this will also apply to portable batteries. They should also provide more information about capacity, performance, lifespan, chemical composition, and the possibility of "separate" collection. (Európsky parlament, 2023)

- **Directive on a Common Charger –** its aim is to reduce the amount of electronic waste by allowing consumers to use just one charger for all devices. The common charging standard will become USB-C. It will apply to various electronic devices such as smartphones, digital cameras, tablets, e-readers, headphones, gaming consoles, speakers, wireless mice and keyboards, etc. The directive will also introduce a pictogram to inform consumers whether a new device will be offered with a charger, as well as a label indicating the charging performance. This is expected to help reduce electronic waste associated with the production, transportation, and disposal of chargers. (Európska únia, 2023)

3.3 Requirements for the Current Ecodesign of Sustainable Products

Rules related to ecodesign are defined by a new legal regulation in the form of the new Ecodesign Regulation, with the aim of delivering high-quality products that are durable, safe, recyclable, and less harmful to the environment throughout their entire lifecycle. Ecodesign incorporates environmental aspects into product development, which manufacturers will need to adapt to. (Kopková, I. - Miklošová, J., 2024).

The requirements arising from the regulation will apply to almost all products, components, and intermediates, with the following exceptions (Kopková, I. - Miklošová, J., 2024):

- *Medicines;*
- *Veterinary medicines;*
- *Live plants, animals, and microorganisms;*
- *Products derived from plants and animals directly related to their reproduction;*
- *Vehicles, insofar as aspects for which requirements are set in sectoral EU legislative acts.*

The reason for addressing ecodesign right from the creation of products lies in achieving the goals (Figure 2):

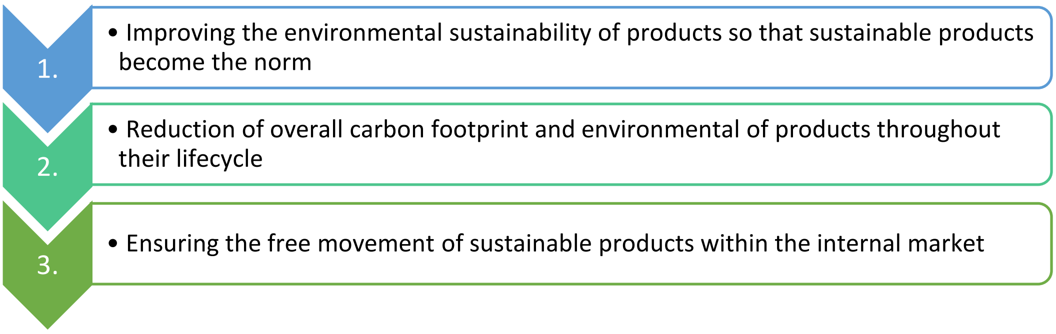

Figure 2. Objectives related to ecodesign

Source: processed according to Kopková, I. - Miklošová, J. (2024)

If a manufacturer wants to place their product on the EU market or into operation, they must meet the following conditions under the regulation: reliability, reusability, upgradability, repairability, maintainability, and renewability, absence of substances of concern, energy consumption and energy efficiency, water consumption and water usage efficiency, resource usage and resource efficiency, recycled material content, material recovery potential, environmental waste, including carbon footprint and expected waste generation.

By respecting these conditions, premature obsolescence of products should be prevented for various reasons, such as the use of less durable components, preventing the disassembly and replacement of key components, or the occurrence of software that no longer works after an operating system update, etc.

Ecodesign requirements will relate not only to the qualitative parameters of the product but also to product information. Products will need to have a digital passport, whose purpose will be (Kopková, I. - Miklošová, J., 2024):

- To ensure easy access to information for entities across the entire value chain and relevant national authorities;
- The data in the product's digital passport must be accurate, complete, and up-to-date;
- Digital product passports must ensure a high level of security and privacy;
- A Product Digital Passport Register will be established (by 2026), along with a web portal for searching the data provided in the digital passport;
- Products may only be placed on the market or into operation based on the digital passport (provided on the product itself, packaging, label, website, app, etc.).

4. Discussion

Sustainable production is a method of manufacturing that minimizes negative environmental impacts, conserves natural resources, and at the same time considers social and economic responsibility. The goal is to produce high-quality products efficiently, ethically, and with regard to future generations.

In the interest of sustainable production, businesses should adhere to the following principles, which also define the current proposals and challenges in this area:

- **Efficient use of raw materials and energy –** reducing the consumption of natural resources, water, and energy throughout the entire production process;
- **Reduction of waste and emissions –** minimizing industrial waste, greenhouse gases, and pollution of air, water, and soil;
- **Use of ecological and renewable materials** – prioritizing recyclable, biodegradable, or certified raw materials;
- **Ethical working conditions** – respecting human rights, ensuring fair wages, and providing a safe environment for employees;
- **Circular economy** – designing products to be repairable, reusable, or recyclable.

5. Conclusion

Product sustainability is currently a necessary path toward creating a balance between economic growth, social well-being, and environmental protection. Sustainable production and consumption should be a joint effort involving manufacturers, distributors, retailers, and consumers, with active support from the state and legislation. It requires responsible decisions from all stakeholders, as it is becoming increasingly important and impactful for the quality of life of future generations.

The main goal of the article was to present the issue and principles of product sustainability. It also included an overview of available sustainability tools, new rules, and requirements related to ecodesign.

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Technology Diffusion in the Age of AI: Comparing Perception and Adoption of Key Technologies

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Abstract: Artificial Intelligence (AI) continues to reshape modern economies and institutions, attracting both unprecedented expectations and critical scrutiny. This paper investigates the extent to which perceived maturity and societal expectations of AI technologies, as represented by the Gartner Hype Cycle (2021–2024), align with their actual adoption rates in business practice, based on OECD/BCG/INSEAD survey data (2025). Using a mixed-method approach, the analysis compares the visibility and lifecycle position of selected AI technologies with empirical evidence drawn from over 1,000 firms across G7 countries and Brazil. The paper identifies clear discrepancies between hype and deployment, particularly for Generative AI and Foundation Models, while also highlighting convergence in more mature domains such as Natural Language Processing and Computer Vision. Findings reveal that many highly publicized technologies remain in early stages of adoption, constrained by organizational readiness, ethical concerns, or regulatory uncertainty. The integration of discursive and empirical perspectives provides a grounded framework for interpreting AI innovation dynamics and informs more realistic expectations for stakeholders. This paper offers implications for AI strategy, public policy, and future research into innovation diffusion, emphasizing the need to bridge the gap between technological aspiration and real-world implementation.

Keywords: artificial intelligence, technology adoption, Gartner Hype Cycle

Introduction

AI has rapidly evolved from a theoretical discipline to a pervasive technological force with significant economic, social, and strategic implications. Its growing role in transforming industries—from healthcare and agriculture to education and logistics—has led to a proliferation of both expectations and challenges. Amid this transformative landscape, understanding the relationship between technological hype and actual adoption is critical for policymakers, businesses, and researchers.

This paper aims to explore the alignment between public and professional expectations of AI technologies, as reflected in the Gartner Hype Cycle, and their real-world adoption rates, as reported by the OECD/BCG/INSEAD (2025) firm-level survey. By integrating discursive models of innovation maturity with empirical data on technology diffusion, the work seeks to reveal not only which technologies are attracting attention but also which are being effectively implemented across sectors.

The analysis proceeds through a structured literature review, an overview of the methodological approach, and a results section that tracks the evolution of AI technologies in the Hype Cycle from 2021 to 2024. These findings are then compared with OECD adoption statistics to assess the extent to which market expectations align with operational realities. The discussion and conclusion offer interpretive insights, practical recommendations, and directions for future research.

1. Literature Review

Definition and Scope of Artificial Intelligence

AI is a multidisciplinary field of computer science devoted to building systems capable of performing tasks that typically require human intelligence. Since John McCarthy coined the term in 1956, AI has evolved from theoretical constructs into practical technologies transforming industries and everyday life (Melak et al., 2024; Nyholm, 2024). AI encompasses domains such as machine learning, deep learning (DL), natural language processing, and robotics, forming the technological basis for intelligent behavior in machines (Mennella et al., 2024; Huawei Technologies, 2023) . While AI includes a broad spectrum of methods, it is commonly divided into narrow AI and general AI (AGI). Narrow AI refers to systems optimized for specific tasks—such as image classification or language translation—whereas AGI aspires to replicate the full range of human cognitive functions (WTTC, 2024) . The current ecosystem is predominantly shaped by narrow AI, although foundational research continues in AGI and hybrid intelligent systems. AI also involves varying degrees of autonomy, from AI merely assisting decision-making to systems acting entirely independently. These levels are increasingly relevant in domains like healthcare, where ethical implications vary with AI's autonomy level (Mennella et al., 2024).

Core Technologies and Applications of AI

The diversity of AI technologies makes classification essential. OECD (2023) identified "core AI patents"—those with high citation impact—that primarily involve technologies such as deep learning, autonomous systems, robotics, and computer vision (Calvino et al., 2023) . These technologies often act as enablers across domains, sparking innovation well beyond their origin sectors. Technologically, two broad approaches define AI algorithms: Rule-based systems: Expert-defined knowledge models that process inputs through logic trees. Data-driven systems (machine learning-based): Algorithms that learn from large data sets to make predictions or decisions, often incorporating neural networks (Mennella et al., 2024). Applications of AI have expanded across all sectors, including healthcare, education, agriculture, and business management. In agriculture, AI is revolutionizing livestock management, enabling farmers to optimize animal health, automate feeding and welfare monitoring, and reduce environmental impacts (Melak et al., 2024). In healthcare, AI enables personalized treatment, diagnostic support, and even remote care delivery through telemedicine and wearable sensors (Mennella et al., 2024). From an economic viewpoint, investment in AI technologies is heavily concentrated in foundational areas such as machine learning and natural language processing. These sectors attract significant capital due to their high potential for cross-sector innovation and value creation (Challoumis, 2024).

Ethical and Regulatory Considerations

With AI's integration into sensitive domains, ethical, legal, and social implications are under intense scrutiny. Issues such as bias, data ownership, privacy, transparency, and accountability are central to current discourse (Katrenčík et al., 2023; Mennella et al., 2024). For instance, biased training data can lead to discriminatory outcomes in hiring, healthcare, or education, disproportionately affecting marginalized groups. AI systems also raise complex questions about responsibility. Who is accountable for decisions made by semi-autonomous or autonomous AI? As Mennella et al. (2024) emphasize, robust regulatory and governance frameworks are essential to balance innovation with societal safeguards. The General Data Protection Regulation (GDPR) in Europe currently serves as the most robust legal framework concerning AI and data usage, but gaps remain in domains such as explainability and cross-border data transfers (Katrenčík et al., 2023). Interestingly, the debate extends to the cognitive implications of AI use. Some scholars argue that AI could lead to human "downgrading" by outsourcing intellectual tasks, while others propose that AI acts as a cognitive enhancer, extending the user’s problem-solving abilities or enabling them to behave in more intelligent ways (Nyholm, 2024).

The Hype Cycle Framework

A critical conceptual model for understanding the evolution and diffusion of AI technologies is the Gartner Hype Cycle. This methodology illustrates the maturity, adoption, and societal expectations of emerging technologies through five phases: Innovation Trigger: A technological breakthrough generates interest, although practical applications are scarce. Peak of Inflated Expectations: Media and public attention spark overenthusiastic projections, often exceeding realistic outcomes. Trough of Disillusionment: Interest wanes as initial implementations fail to deliver, exposing technological and practical limitations. Slope of Enlightenment: Gradual improvement and understanding emerge, supported by real-world experimentation. Plateau of Productivity: The technology achieves mainstream adoption and stable value generation. This model is particularly relevant to AI, which has historically followed cyclical waves of excitement and stagnation. For example, early enthusiasm around expert systems in the 1980s gave way to disillusionment, only for new surges to arise with machine learning and generative AI (Huawei Technologies, 2023) . Understanding where specific AI technologies lie on the Hype Cycle helps stakeholders make informed decisions regarding investment, adoption, and policy.

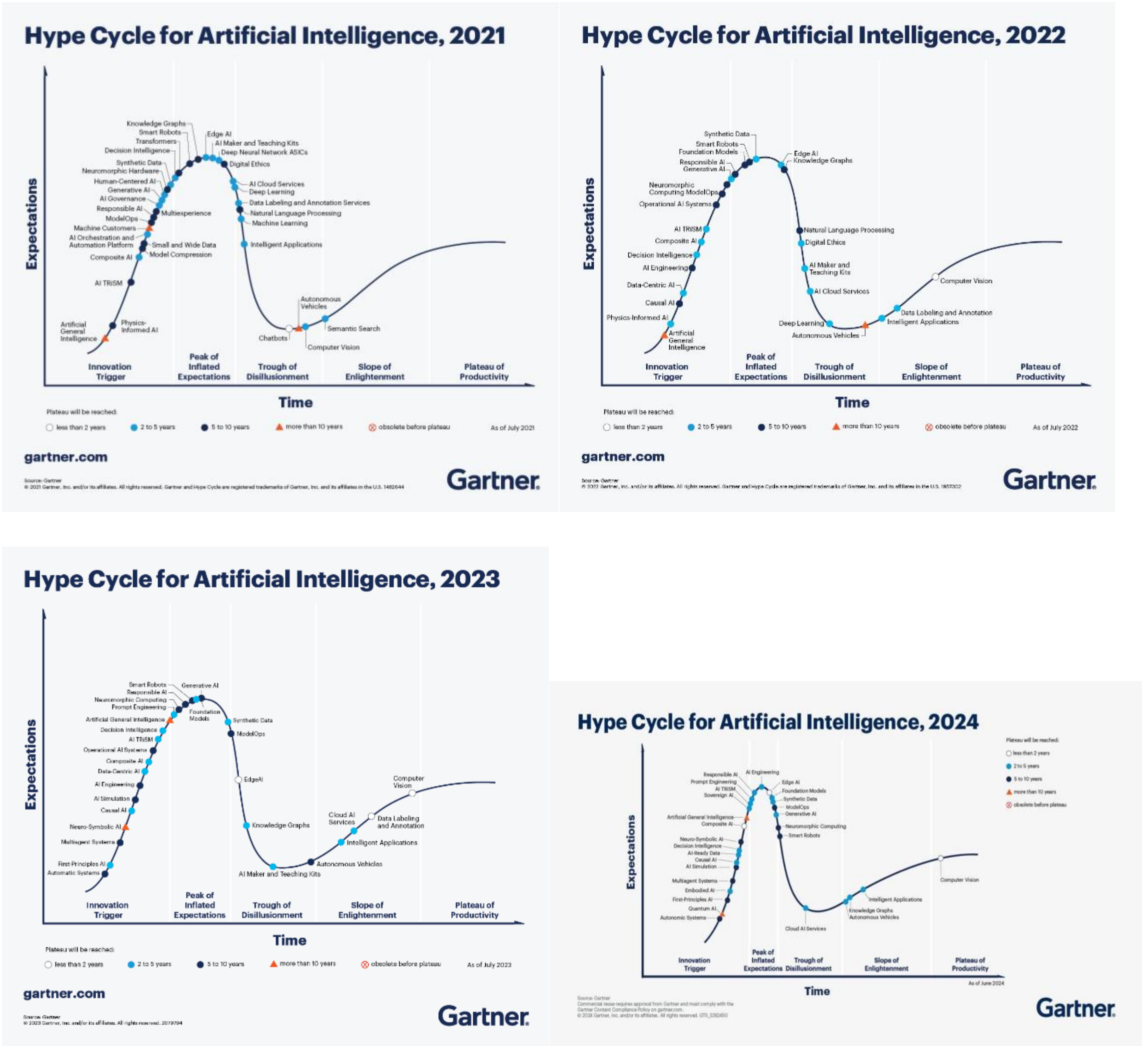

Figure 1. Hype Cycle Application on AI technologies (2021-2024)

Source: gartner.com

Diffusion and Current Trends in AI Technologies

According to McKinsey (2025), more than 75% of surveyed organizations report using AI in at least one business function, with larger firms accelerating adoption due to greater resources and structured governance (Singla et al., 2025). Workflow redesign, senior leadership engagement, and ethical oversight are positively correlated with AI's bottom-line impact. The education sector offers a compelling illustration of this diffusion. Tools like ChatGPT have prompted universities to reassess academic integrity policies, as students simultaneously exploit and resist generative AI for coursework (Johnston et al., 2024). While some students view these tools as assistive technologies, others express concern over dependency and fairness—highlighting the need for inclusive, clearly defined guidelines. In healthcare, AI-based decision support systems are transforming diagnostics, resource allocation, and personalized care. Nevertheless, such integration remains fraught with regulatory ambiguity and ethical dilemmas, especially around accountability and autonomy (Mennella et al., 2024). In agriculture, AI's diffusion reflects the technology's ability to address real-world challenges such as food security and climate change. Applications range from disease monitoring to efficient feeding and sustainability tracking (Melak et al., 2024). Finally, from a macroeconomic perspective, AI capital investment patterns reflect a growing consolidation of influence among large tech companies. Challoumis (2024) notes that over 70% of global AI investment is concentrated in the hands of a few top-tier firms, with machine learning and natural language processing technologies attracting the most funding.

Summary

AI is not just a set of technologies—it is a transformative force redefining the boundaries of human cognition, industrial operations, and ethical responsibility. As demonstrated through diverse applications and governance models, AI's trajectory is best understood via frameworks such as the Hype Cycle, which illuminate both the optimism and realism required in managing technological change. Ethical considerations, regulatory developments, and socio-economic impacts will shape not only how AI diffuses but also how it is accepted by society. As the boundaries between human and machine intelligence blur, the challenge will not only be in building smarter systems but also in ensuring they align with the principles of trust, transparency, and human well-being.

2. Methodology

The aim of this paper is to systematically compare the expectations surrounding key artificial intelligence technologies—as reflected in the Gartner Hype Cycle—with their actual levels of adoption by firms, as captured in recent OECD/BCG/INSEAD survey data. By bridging these two complementary perspectives, the research seeks to identify alignment or divergence between public discourse and real-world implementation, and to derive actionable insights for policymakers and innovation strategists. The methodological approach of this paper is based on a comparative and integrative framework that combines qualitative trend analysis with empirical data evaluation. The methodology proceeds in three key stages:

(1) Analysis of Gartner Hype Cycle Reports (2021–2024): The first stage involved a longitudinal content analysis of Gartner's annual Hype Cycle for Artificial Intelligence reports from 2021 to 2024. These visual frameworks were used to trace the evolution of specific AI technologies over time, with particular attention to their position within the five-phase Hype Cycle model: Innovation Trigger, Peak of Inflated Expectations, Trough of Disillusionment, Slope of Enlightenment, and Plateau of Productivity. Technologies were catalogued, grouped thematically, and compared across years to identify emerging trends, shifts in perceived maturity, and the appearance or disappearance of specific innovations.

(2) Empirical Mapping Using OECD/BCG/INSEAD Survey Data (2025): The second stage relied on empirical data provided in the 2025 OECD/BCG/INSEAD report titled "The Adoption of Artificial Intelligence in Firms: New Evidence for Policymaking." This source presents adoption data from more than 1,000 firms across G7 countries and Brazil. The survey covers a broad spectrum of AI applications and industries. Adoption rates were extracted for selected technologies—particularly those also featured in the Gartner Hype Cycle. Where direct equivalence was not possible, conceptual groupings were applied (e.g., Natural Language Processing representing both Generative AI and Prompt Engineering).

(3) Synthesis and Comparative Interpretation: The final stage involved the synthesis of discursive and empirical findings. A side-by-side comparison was constructed for technologies that appeared in both the Hype Cycle and OECD survey. Technologies were assessed for alignment or misalignment between their perceived maturity (as indicated by Gartner) and actual adoption levels (as observed in the OECD data). Thematic interpretation was applied to explore underlying causes of gaps or convergences, such as organizational readiness, technical complexity, regulatory challenges, or ethical concerns.

Throughout the process, methodological triangulation was applied to increase the robustness of findings by cross-referencing multiple sources. The approach prioritizes clarity, comparative logic, and transparency in interpretative mapping. This method was selected to enable both a high-level overview of trends and a grounded insight into adoption realities.

3. Results

This chapter presents the core analytical findings of the work by integrating two complementary perspectives: (1) the trend-based assessment of artificial intelligence technologies based on the Gartner Hype Cycle (2021–2024), and (2) the empirical evidence on adoption rates derived from the OECD/BCG/INSEAD survey (2025). Together, these perspectives offer a multidimensional view of how expectations around AI technologies evolve and how these expectations translate—if at all—into real-world deployment.

3.1. Changes in the Number and Type of Technologies

Between 2021 and 2024, the Gartner Hype Cycle for Artificial Intelligence illustrates dynamic shifts in the positioning of technologies across different phases, as well as the emergence of new concepts. In 2021, the graph featured more than 30 technologies, primarily concentrated in the "Innovation Trigger" and "Peak of Inflated Expectations" phases. In the subsequent years, the number of listed technologies fluctuated between 30 and 35, indicating a consistent interest in innovation within the AI domain, alongside the rotation and replacement of older technologies with novel concepts. For instance, technologies such as AI Governance, Digital Ethics, and Model Compression—present in 2021—either disappeared from later editions or were redefined under new conceptual labels (e.g., Responsible AI or Operational AI Systems). Conversely, technologies like Foundation Models (introduced in 2022), Prompt Engineering (2023), Sovereign AI (2024), and AI-Ready Data reflect the growing practical importance of generative models and the increasing interest in sovereignty over AI infrastructure.

3.2. Key Technological Trends

Among the most prominent trends is the clear rise of Foundation Models and Generative AI, which first appeared in the Hype Cycle in 2022 and have since maintained their position near the peak of inflated expectations. These technologies reflect the rapid proliferation of models such as GPT, BERT, DALL·E, and other large language or generative models. In 2023 and 2024, complementary concepts such as Prompt Engineering and Responsible AI emerged to address the practical deployment and ethical implications of these models. Another key trend is the rise of technologies focused on AI operationalization (e.g., ModelOps, Operational AI Systems, AI Engineering), signaling a shift from experimental laboratory solutions toward practical implementation in enterprise environments. Simultaneously, we observe the development of concepts like AI TRiSM (Trust, Risk, and Security Management), Decision Intelligence, and Neuro-Symbolic AI, which represent a collective effort to build more robust, explainable, and less opaque ("black-box") AI systems. In contrast, technologies such as Chatbots, Deep Learning, and AI Cloud Services—which in 2021 were among the dominant themes—have gradually lost prominence, transitioning toward the "Trough of Disillusionment." This reflects their commoditization and declining perceived innovation potential. Autonomous Vehicles occupy a special position, remaining within the disillusionment phase across all four years, highlighting persistent barriers to real-world deployment.

3.3. Dynamics of Expectations and Discourse

In terms of public discourse and expectations, a significant shift is evident—from technologically focused solutions (e.g., Deep Learning, Computer Vision) toward systems with broader implications for decision-making, productivity, and content generation. Issues related to control and sovereignty, such as Sovereign AI and AI-Ready Data, have moved to the forefront, driven by geopolitical pressures and the growing demand for localization of AI solutions. Increasing attention is also being paid to explainability, ethics, fairness, and robustness. Furthermore, tools for risk management and accountability are gaining visibility, as they are considered essential for the scalable and trustworthy deployment of AI.

3.4. Comparison of Time to Plateau

From the perspective of projected timelines for reaching the "Plateau of Productivity," technologies such as Computer Vision, Data Labeling and Annotation, and Intelligent Applications are approaching wide-scale adoption and are expected to mature within two years. In contrast, technologies such as Artificial General Intelligence, Quantum AI, Neuro-Symbolic AI, and Autonomic Systems are classified as long-term concepts with expected timelines exceeding ten years. Other technologies, including Foundation Models, ModelOps, Generative AI, and Edge AI, are projected to reach maturity within five to ten years. This suggests a combination of rapid advancement and the need for additional time to support broad adoption and stabilize the associated technical, ethical, and legal frameworks.

3.5. Empirical Comparison of Hype and Adoption of Selected AI Technologies

In order to provide a more robust and reality-anchored assessment of artificial intelligence technologies, we complement the trend analysis based on Gartner's Hype Cycle with empirical data on actual adoption rates. This comparison enables a clearer understanding of the extent to which highly publicized technologies are already being utilized in practice and reveals potential discrepancies between market expectations and real-world application.

Due to differences in categorization and terminology, a one-to-one mapping of technologies between the Gartner Hype Cycle and the OECD/BCG/INSEAD adoption survey is not always possible. However, many of the broader technological categories overlap conceptually and functionally. For example, the OECD report identifies "Natural Language Processing" as a key application area, which encompasses several specific technologies featured in the Hype Cycle, such as Prompt Engineering and Generative AI. Similarly, "Machine Learning" in the OECD data includes a wide range of technologies found under labels like Foundation Models, AI Engineering, and ModelOps in the Hype Cycle. While these conceptual mappings are not perfect, they reflect meaningful clusters of functionality and application that justify comparative analysis.

Drawing on the OECD/BCG/INSEAD (2025) survey report, which comprises data from over 1,000 firms across G7 countries and Brazil, we identify eight key technologies that are both represented in the Hype Cycle 2024 and quantitatively covered in the adoption dataset. These include core technologies such as Machine Learning, Natural Language Processing, and Generative AI, as well as more specialized applications such as Edge AI and Autonomous Vehicles.

The following comparative analysis presents each technology’s current placement in the Hype Cycle, its empirically observed adoption rate, and an interpretative assessment of the gap between hype and adoption.

(1) **Machine Learning Hype Cycle Placement**: Implicitly embedded in foundational and operational AI technologies. Adoption Rate: Approximately 30–35% of AI-adopting firms in the UK utilize machine learning; general adoption in U.S. firms across sectors is around 6.6%. Gap Between Hype and Reality: While foundational to modern AI systems, machine learning’s actual deployment remains limited due to high data demands and talent shortages, especially among SMEs.

(2) **Natural Language Processing Hype Cycle Placement**: At the Peak of Inflated Expectations via related technologies such as Prompt Engineering and Generative AI. Adoption Rate: Over 50% of UK firms that use AI have adopted natural language processing applications, particularly in customer-facing roles. Gap Between Hype and Reality: This technology represents a rare case of convergence between hype and practice, supported by increasing commercial adoption and real-world utility.

(3) **Computer Vision Hype Cycle Placement:** Plateau of Productivity. Adoption Rate: Utilized by approximately 12.4% of U.S. manufacturing firms. Gap Between Hype and Reality: The maturity and reliability of this technology are reflected in its practical uptake, especially in quality control and automation.

(4) **Generative AI / Foundation Models Hype Cycle Placement**: Peak of Inflated Expectations. Adoption Rate: Estimated adoption ranges between 15–20% in mid- to large-size firms (based on external data sources). Gap Between Hype and Reality: Rapid uptake is occurring, particularly in product design and HR, but challenges with trust, hallucinations, and integration slow full adoption.

(5) **AI Cloud Services Hype Cycle Placement**: Trough of Disillusionment. Adoption Rate: General cloud adoption among firms ranges between 74–84%, with lower figures for AI-specific use. Gap Between Hype and Reality: While cloud infrastructure is widely adopted, usage for AI applications remains fragmented and often limited to large firms with sufficient digital readiness.

(6) **Industrial AI / Robotics for Fabrication Hype Cycle Placement**: Slope of Enlightenment. Adoption Rate: Fewer than 12.4% of manufacturing companies report using AI-enhanced robotics. Gap Between Hype and Reality: Integration is constrained by high implementation costs, legacy systems, and limited digital ecosystems in traditional manufacturing.

(7) **Edge AI Hype Cycle Placement**: Slope of Enlightenment. Adoption Rate: Adoption remains sector-specific (e.g., automotive, IoT), with no precise general percentage available. Gap Between Hype and Reality: Despite technical maturity, adoption is limited by the complexity of deployment environments and infrastructure requirements.

(8) **Autonomous Vehicles Hype Cycle Placement**: Trough of Disillusionment. Adoption Rate: Negligible adoption outside of pilot programs. Gap Between Hype and Reality: This technology exhibits the largest gap between hype and adoption, limited by unresolved regulatory, safety, and technical challenges.

Overall, this analysis demonstrates that while some technologies—such as natural language processing and computer vision—have transitioned into practical applications in alignment with their perceived maturity, others such as AGI, Quantum AI, or Autonomous Vehicles remain largely aspirational. Incorporating empirical adoption data provides a more nuanced interpretation of the Hype Cycle and enables stakeholders to identify realistic opportunities and risks in the diffusion of AI technologies.

Table 1. Hype Cycle vs. Reality: Summary for selected AI technologies

Technology	Hype Cycle Phase	Adoption Rate (% of firms)	Gap Comment
Machine Learning	Embedded / Mature	~6.6% (US), ~30% (UK firms using AI)	Moderate gap due to complexity
Natural Language Processing	Peak of Expectations	>50% (UK AI firms)[1]	Low gap, strong alignment
Computer Vision	Plateau of Productivity	12.4% (US manufacturing	Aligned
Generative AI	Peak of Expectations	~15–20% (external est.)	High gap, adoption still emerging
AI Cloud Services	Trough of Disillusionment	74–84% (cloud usage)	Aligned in infrastructure, limited for AI
Industrial AI / Robotics	Slope / Plateau	12.4% (manufacturing	Adoption lagging
Edge AI	Slope of Enlightenment	Sector-specific usage	Growing, not mainstream yet
Autonomous Vehicles	Trough of Disillusionment	Negligible	Hype far ahead of adoption

Source: own processing based on the used references

4. Discussion

The analysis presented in the preceding chapter offers a detailed account of both the evolution of AI technologies in the public and professional discourse, as well as their real-world diffusion among firms. Several key observations emerge from the synthesis of the Gartner Hype Cycle data and the OECD/BCG/INSEAD adoption report.

First, the comparison reveals a structural divergence between perceived technological maturity and actual adoption levels. Technologies like Generative AI and Foundation Models have rapidly ascended to the peak of expectations, driven by the proliferation of high-profile models (e.g., GPT, DALL·E). Yet despite their visibility and innovation potential, real-world deployment remains limited, primarily due to challenges in integration, cost, and trust. Conversely, some technologies such as Computer Vision and Machine Learning, while receiving less attention in recent hype cycles, exhibit higher degrees of operational maturity and are already being adopted across industries.

Second, the presence of adjacent or derivative concepts in the Hype Cycle—such as Prompt Engineering, Responsible AI, and ModelOps—illustrates the growing ecosystem around core AI capabilities. These reflect increasing specialization and the practical need for explainability, control, and trust in deployment contexts. However, as shown by the empirical data, their adoption remains in early stages and concentrated in digitally advanced firms.

Third, the limited progress of certain long-standing technologies, such as Autonomous Vehicles, highlights the persistence of technical and systemic barriers, even in areas that once attracted significant investment and media attention. The sustained position of this technology in the Trough of Disillusionment is emblematic of a broader gap between technological ambition and regulatory or infrastructural feasibility.

Finally, the empirical adoption data help qualify the predictive power of the Hype Cycle by grounding it in firm-level realities. The layered nature of AI implementation—often requiring large-scale organizational transformation—explains why some technologies, although conceptually mature, experience slower uptake in practice. As such, interpreting hype without reference to adoption data risks overstating the immediacy or breadth of AI-driven transformation.

All in all, the combination of discursive and empirical perspectives not only enriches the understanding of AI innovation dynamics but also provides a more pragmatic basis for decision-making among policymakers, investors, and organizational leaders. This approach underscores the importance of distinguishing between what is technologically possible and what is practically implementable.

5. Conclusion

This paper examined the evolution and practical relevance of artificial intelligence technologies by comparing the Gartner Hype Cycle with empirical adoption data from the OECD/BCG/INSEAD survey. The dual perspective offered a nuanced understanding of the disconnect—and occasional alignment—between technological hype and real-world implementation.

The results reveal that while certain technologies such as Natural Language Processing and Computer Vision have achieved a balanced alignment between perceived potential and adoption, others—most notably Generative AI and Autonomous Vehicles—highlight significant discrepancies between visibility and actual use. This disparity underscores the importance of contextualizing emerging AI trends not only within discursive frameworks, but also within the structural and operational realities of firms.

Several key recommendations emerge from this analysis: Policymakers should prioritize support for technologies showing both strong potential and a clear path to adoption, such as Machine Learning and operational AI tools. Efforts should be made to enhance explainability, trust, and integration capacity for high-hype but under-adopted technologies like Generative AI. Investment in skills development and AI infrastructure should accompany regulatory frameworks to accelerate meaningful and ethical AI diffusion.

This work also highlights important limitations. The Gartner Hype Cycle is a perception-driven model and may not fully capture sector-specific nuances. Meanwhile, the OECD adoption data, although comprehensive, reflects only a specific set of countries and industries. Additionally, the conceptual mapping between Hype Cycle categories and firm-level technologies necessitates some degree of interpretative approximation.

Future research could build on this foundation by incorporating longitudinal adoption data, sector-specific case studies, or integrating other strategic frameworks such as technology readiness levels (TRL) or innovation diffusion models. In particular, more granular analyses by firm size, industry, and geographic context could provide actionable insights into the heterogeneous nature of AI transformation. Ultimately, the integration of perceptual and empirical analyses provides a clearer roadmap for understanding the real trajectory of AI technologies, and for designing policies and strategies that are both ambitious and grounded in reality.

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Differences in AI readiness across EU countries: Empirical segmentation and recommendations

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Abstract: This study analyses the level of development of artificial intelligence (AI) in the Member States of the European Union through a quantitative classification based on Eurostat data. The aim is to identify differences in the adoption and development of AI across countries, taking into account economic and research capacities. The analytical framework uses variables such as GDP per capita, share of researchers, in-house AI development, use of AI technologies and their purposeful deployment in enterprises of different sizes. Using hierarchical clustering analysis (Ward method), countries were divided into three segments with different profiles: technological leaders with high research activity, economically advanced countries with low AI integration and developing countries with limited research background. The results show that the size of enterprises, the level of digitalisation and research support significantly affect the ability of countries to implement AI. Based on the findings, targeted recommendations for policy and economic strategy in the field of digital transformation are formulated. The study contributes to a better understanding of differences in AI readiness and use and offers an empirically based basis for designing differentiated development strategies within the EU.

Keywords: artificial intelligence, EU countries, hierarchical cluster analysis, technology adoption

Introduction

In recent years, artificial intelligence (AI) has established itself as a key technology of the 21st century. Artificial intelligence (AI) is increasingly being used to address global challenges such as climate change, healthcare, food security and social inequality. Advances in machine learning, deep neural networks and computing power have significantly expanded the capabilities of AI systems. These advances are not only used in industry, but also in solving complex global challenges (Vinuesa et al., 2020). Given the growing dependence of society on technology, it is necessary to monitor not only technological developments, but also their social impacts.

1. Literature Review

The growing importance of artificial intelligence (AI) in the economy and society has raised the need to understand not only technological aspects, but also regional differences in the rate of its adoption, development and use. In the last decade, several approaches to assessing AI in terms of political readiness, economic capacities and innovative capacity of countries have appeared in the literature. Classic studies already emphasize that AI is not just a technology, but is becoming a key production factor. Brynjolfsson and McAfee (2017) describe AI as the driving force of the so-called second digital era, in which economic growth and productivity depend on the ability of countries and firms to integrate algorithmic decision-making into their processes. In this context, AI is directly linked to the performance of businesses and the long-term competitiveness of states (Bughin et al., 2019). According to studies by the OECD (2021) and the European Commission (2023), significant regional differences in the rate of digitalization and the ability to apply AI persist between EU countries. These differences stem not only from technological readiness, but also from different levels of human capital, research capacities and investment environment. Digital inequality thus becomes a significant factor of economic divergence within the Union. Several authors have attempted to create indices or frameworks for assessing the so-called AI Readiness (Oxford Insights, 2022), which take into account factors such as research and development (R&D), investment, regulation, data infrastructure and education. However, these frameworks often operate at the level of national strategies and are less focused on the real implementation of AI in business practice. Empirical research (Ace-moglu & Restrepo, 2020; EIB, 2022) suggests that company size is a significant predictor of the adoption of AI technologies. Larger companies have not only the capital, but also the analytical and IT capabilities necessary to develop or implement complex solutions. On the contrary, small and medium-sized enterprises (SMEs) face higher barriers – from a lack of experts to concerns about the return on investment. The use of hierarchical cluster analysis (HCA) to classify countries according to AI indicators is so far less represented in the literature. Some studies (e.g. Vinuesa et al., 2020) apply classification methods to track progress in sustainable development and AI, but segmentation based on real AI activity in businesses and research – as in this study – provides new insight into the effectiveness of implementing digital strategies in individual countries.

2. Methodology

The aim of this study was to analyse and classify European Union countries according to their level of adoption of artificial intelligence (AI) and related economic and research indicators. The research relied on secondary data from the Eurostat database, which provides harmonised statistics on business activity and innovation in the EU Member States. The analysis used data from 2023–2024 on the use and development of AI technologies in enterprises by size categories (10–49, 50–249 and 250+ employees). Additional variables included: GDP per capita in current prices (EUR) as an indicator of economic maturity, the share of researchers in the workforce (in full-time equivalent), the share of enterprises that: use at least one AI technology (AI adoption), use AI for a specific purpose (AI by purpose) and develop AI internally by their own employees (AI developed in-house). The overall dataset contained quantitative data for 27 EU countries. All variables were numerically harmonized and any missing values were excluded from the clustering analysis. The resulting matrix contained ten quantitative indicators for each country. To identify similarities between countries, a hierarchical clustering method was used. The Euclidean distance was chosen as the distance metric, which is suitable for comparing multiple quantitative features. The Ward method was used to merge clusters. The clustering results were illustrated using a dendrogram, which allows identifying the natural number of segments. Countries were grouped into three main segments (clusters) according to their position in the field of artificial intelligence. The data were processed using the marketing analytical program Enginius.

2. Results

The results of the hierarchical cluster analysis confirmed the existence of three significantly different segments of EU countries in terms of the development and use of artificial intelligence. The first segment includes economically advanced countries with high GDP, which, however, show a relatively low rate of AI adoption outside of large enterprises. The second segment consists of technology leaders that combine a strong research base, extensive internal development of AI solutions and a high share of enterprises using AI in practice. The third segment represents emerging economies with limited research and technological capacities, where AI is penetrating slowly and mainly in the form of external services. These differences indicate the need for asymmetric but coordinated policies that take into account the specific needs of individual groups of countries. The detailed results of the hierarchical cluster analysis are presented in Figure 1 and Table 1. Segment 1 is the smallest and contains one country, segment 2 six countries and segment 3 fifteen countries. The description of the segments is expressed by the average value of each segmentation variable, overall for each segment. Segmentation variables that are statistically different from the rest of the population are highlighted in red (lower) or green (higher).

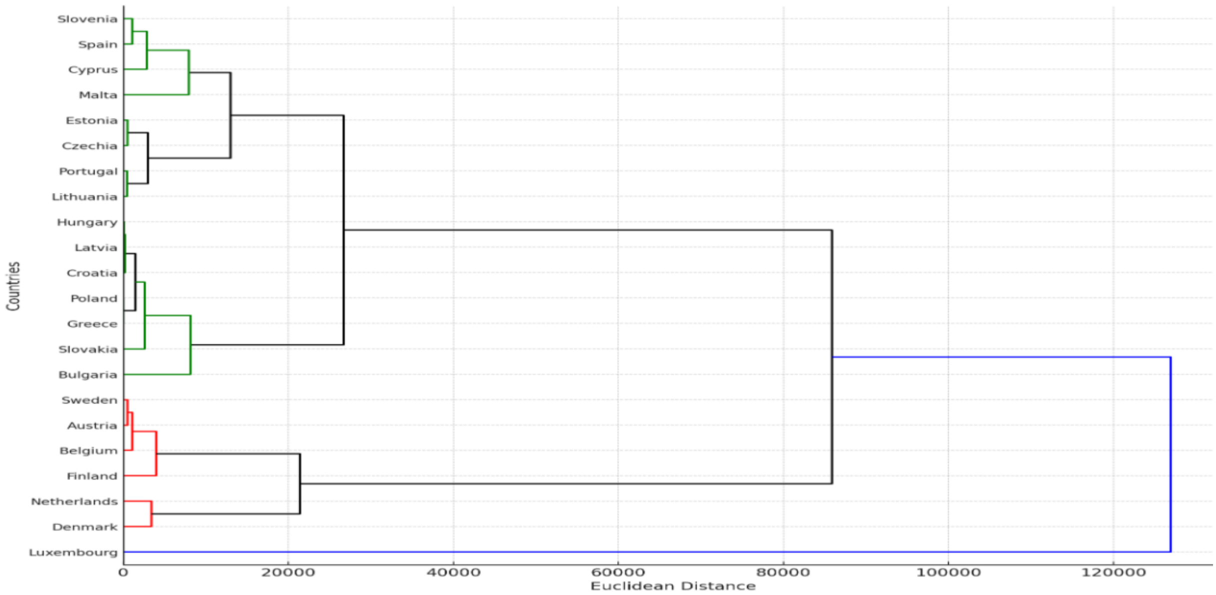

Figure 1: Clustering of Countries by Selected Indicators of In-House AI Development (2024)
Source: Own processing in Enginius.

Table 1: Segment Description: Average Values of Selected Variables by Country Cluster in %.

	Segment 1	Segment 2	Segment 3
10 own	3.45	3.81	1.87
50 own	6.32	8.24	4
250 own	14.8	20	11.2
GDP	126 910	55 990	26 662
R&D researchers	1.184	2.23	1.14
10 AI	21.12	20.68	8.87
250 AI	45.6	60.1	35.3
10 pur	12.14	15.38	6.89
50 pur	19.1	27.8	13.4

Source: Own processing in Enginius.

Explanatory notes:

10 own	From 10 to 49 persons employed, % Enterprises' AI technologies were developed by own employees
50 own	From 50 to 249 persons employed, % Enterprises' AI technologies were developed by own employees
250 own	250 persons employed or more, % Enterprises' AI technologies were developed by own employees
GDP	Gross domestic product at market prices, Current prices, euro per capita
R&D researchers	Percentage of population in the labour force - numerator in full-time equivalent (FTE)
10 AI	From 10 to 49 persons employed, % Enterprises use at least one of the AI technologies: AI_TTM, AI_TSR, AI_TNLG, AI_TIR, AI_TML, AI_TPA, AI_TAR
50 AI	From 50 to 249 persons employed, % Enterprises use at least one of the AI technologies: AI_TTM, AI_TSR, AI_TNLG, AI_TIR, AI_TML, AI_TPA, AI_TAR
250 AI	250 persons employed or more, % Enterprises use at least one of the AI technologies: AI_TTM, AI_TSR, AI_TNLG, AI_TIR, AI_TML, AI_TPA, AI_TAR
10 pur	From 10 to 49 persons employed, % Enterprises use AI technologies for at least one of the purposes: AI_PMS, AI_PPP, AI_PBAM, AI_PLOG, AI_PITS, AI_PFIN, AI_PRDI
50 pur	From 50 to 249 persons employed, % Enterprises use AI technologies for at least one of the purposes: AI_PMS, AI_PPP, AI_PBAM, AI_PLOG, AI_PITS, AI_PFIN, AI_PRDI
250 pur	250 persons employed or more, % Enterprises use AI technologies for at least one of the purposes: AI_PMS, AI_PPP, AI_PBAM, AI_PLOG, AI_PITS, AI_PFIN, AI_PRDI

Analysis of advanced countries with high economic strength and average AI activity. (Segment 1, Luxembourg) Includes countries with exceptionally high economic performance (GDP per capita over €120,000) and at the same time with a medium-high level of adoption and development of artificial intelligence (AI) in the business sector. This segment represents a unique group of countries where there is a high potential for technological progress, but at the same time there is a selective and strategic deployment of AI technologies. The average gross domestic product (GDP) in this segment reaches €126,910 per capita, which far exceeds the EU average. At the same time, research capacity – measured as the share of researchers in full-time equivalents – represents 1.184% of the workforce. This indicates a high innovation potential and a favorable environment for technology transfer between academia and business. The share of companies that develop their own AI solutions through their own employees increases with the size of the company: in companies with a lower number of employees from 10 to 49, only 3.45% of companies develop their own AI solutions, in companies with 20-249 employees it is 6.32% of companies and in companies with more than 250 employees up to 14.8% of companies develop their own AI solutions. These values indicate a higher level of technological sovereignty and investment in internal know-how compared to the second and third segments. The use of at least one of the main AI technologies (e.g. speech recognition, natural language, predictive analysis, etc.) is relatively widespread: in companies in the 10-49 employee category it is 21.12% of companies and in the 250+ employee category it is 45.6%. These values show that AI is commonly present in business processes, especially in large organizations. Businesses in this segment use AI mainly for process optimization, predictions, logistics and financial decision-making in 12.14% of businesses (10–49 employees) and 19.1% of businesses (50–249 employees), with higher shares expected for large companies. These data confirm the trend of using AI technologies to increase efficiency and profitability. Segment 1 represents high-performance economies that are characterized by selective and strategic deployment of AI technologies. Despite the high availability of capital and research potential, AI adoption is not universal; this segment can be characterized as "economically strong but AI-cautious" meaning greater caution or emphasis on qualitative use over quantity.

Technological innovators with high levels of AI adoption. (Segment 2) Based on the grouping according to selected indicators, the following countries belong to Segment 2: Belgium, Denmark, the Netherlands, Austria, Finland and Sweden. We call them technological innovators with high levels of AI adoption. This segment represents a group of technologically advanced European countries that combine high investments in research and development (R&D) with active deployment of artificial intelligence (AI) in the business environment. These countries are often leaders in the field of innovation, digitalization and the knowledge economy. The average gross domestic product in this segment reaches EUR 55,990 per capita, which is above the EU average. The share of researchers in the workforce is 2.23%, which is one of the highest shares in Europe. These figures demonstrate systematic support for research and technological innovation. The share of companies that develop their own AI solutions internally is significantly above average in this segment: with a number of employees from 10–49 employees, it is 3.81% of companies, with a number of employees from 50–249 employees, it is 8.24%, and with a number of employees over 250, it is 20.0% of companies that develop their own AI solutions internally. This indicates that companies are not only users of technologies, but also their active creators, and have professional staff and research capacities. The use of at least one AI technology is very widespread, especially in larger companies with over 250 employees, up to 60.1% of companies use at least one AI technology, and in companies with a number of employees from 10–49, it is 20.68% of companies. These values confirm technological maturity, as well as the willingness to implement AI solutions in company practice. AI is becoming a part of everyday activities, especially in large organizations. The purposeful use of AI – for example, in the area of customer behavior prediction, process automation or financial decision-making – is also at a high level: 15.38% in companies with 10–49 employees, 27.8% in companies with 50–249 employees, and even more 58.37% in large companies with more than 250 employees. These figures reflect the high commercial value and practical deployment of AI across various segments of the economy. Countries in Segment 2 can be characterized as "technological innovators" who: systematically invest in research and development, are able to independently develop sophisticated AI solutions, and at the same time effectively implement them in practice (Terblanche & Kidd, 2022). This model represents the highest level of AI maturity, where AI is not just a tool, but also a key part of corporate strategy and economic growth.

Emerging economies with limited AI integration. (Segment 3) The third segment represents a group of countries with a lower level of digitalization and integration of artificial intelligence (AI) in business practice. These countries include: Slovenia, Spain, Cyprus, Malta, Estonia, Czechia, Portugal, Lithuania, Hungary, Latvia, Croatia, Poland, Greece, Slovakia, Bulgaria. Although they are mostly EU Member States, their economic and technological level indicates challenges in the field of innovation, research and adoption of digital technologies. These countries represent a great potential for growth if there is systemic support and investment in AI infrastructure and talent. The average GDP per capita in this segment reaches EUR 26,662, which is significantly below the EU average. The share of researchers in the workforce is only 1.14%, which indicates limited personnel capacities for the development and application of innovative technologies. Businesses in these countries show relatively low rates of internal AI development: 1.87% for businesses with 10–49 employees, 4.00% for businesses with 50–249 employees, and 11.20% for businesses with more than 250 employees. These figures indicate a dependence on external technology vendors or a slower development of in-house AI capabilities. The adoption of basic AI technologies is significantly lower than in other segments: 8.87% for businesses with 10–49 employees and 35.30% for businesses with more than 250 employees. Although large businesses show some degree of adaptation, AI technology penetration is still very low in smaller firms. Purposeful use of AI (e.g. predictive modeling, automation, logistics) is limited in this segment: 6.89% for companies with 10–49 employees, 13.40% for companies with 50–249 employees, even in the largest companies these values are below the level of the first and second segments, i.e. 29.32%. Segment 3 consists of countries that face various structural and technological barriers to the adoption of artificial intelligence. A weaker research base, lower GDP and limited internal capacities create an environment where the development of AI is more challenging. At the same time, however, this segment represents the greatest potential for catching up with the rest of the EU, if targeted investments, education reform and digitalization policies are implemented.

4. Discussion

The results of the cluster analysis show significant differences between EU countries in the area of artificial intelligence integration. The three segments that emerge reflect not only the technological level and availability of research capacities, but also the institutional environment and economic capabilities of enterprises. Segment 1, which includes Luxembourg, has the highest GDP, but its use of AI is less widespread and mainly concentrated in large enterprises. This may signal caution or concentration of AI in specific sectors. Segment 2, which includes countries such as Denmark, Finland, the Netherlands and Sweden, is profiled as a technological leader, with a high share of internal AI development and active use of intelligent solutions in business practice. These countries have already moved from the experimentation phase to the strategic integration of AI into management and innovation. Segment 3 includes most of the Central and Eastern European countries, which face structural challenges: lower share of researchers, weaker digital infrastructure and limited penetration of AI technologies in small and medium-sized enterprises. These differences indicate the need for targeted policies tailored to the specificities of individual country groups. The results of the analysis showed that the European Union countries are at different stages of development and integration of artificial intelligence (AI), while the current pace of adoption and the level of research capacities indicate the need for differentiated approaches. Based on the identified segments, it is possible to formulate specific strategic recommendations that can support the balanced development of AI across EU Member States.

4.1. Strategies and recommendations for supporting the development of artificial intelligence in individual segments.

Strategic AI Deployment in Economically Advanced Countries with Low Adoption Rates in Segment 1. Highly advanced countries with above-average GDP, such as Luxembourg, show relatively low rates of AI integration outside of large enterprises. These countries have the potential for broader AI deployment in the economy, but require a strategy focused on diversifying applications. It is recommended that:

- Support broader sectoral adoption of AI, especially in traditional industries (logistics, healthcare, public administration), which often lag behind technology companies (Lešková, 2024).
- Support the entrepreneurial innovation environment, especially startups, through simplified access to financing, mentoring.

- Implement national strategies for responsible and ethical AI that take into account the rights of individuals, the transparency of algorithms and the fairness of decision-making processes.
- Intensify cooperation between the public and private sectors in the development and deployment of AI solutions, especially in the area of public services and infrastructure (Upadhyay et al., 2022).

Consolidation and international strengthening of the position of technological leaders, recommendations for segment 2. Countries such as Denmark, Finland, the Netherlands or Sweden have already achieved a high degree of AI integration and are characterized by a strong research base as well as the extensive use of intelligent systems in industry and services. The challenge for these countries is not expansion, but qualitative deepening and internationalization of AI ecosystems. Strategic measures may include:

- Support for explainable, transparent and trustworthy AI (XAI) as a new standard, thereby strengthening the trust of citizens, customers and regulators (Chatterjee et al., 2024).
- Development of international research consortia, common data spaces and AI platforms that connect universities, development centers and businesses at a transnational level.
- Introduction of regulatory frameworks and ethical standards that can serve as a model for other countries, thus making countries global AI policymakers (Chaudhuri et al., 2024).
- Supporting technology transfer to less developed parts of the EU, thereby reducing the digital divide and strengthening cohesion between Member States.

Supporting AI development in emerging economies in segment 3. Countries with lower GDP and limited research infrastructure face challenges in digitalization, technical readiness and access to talent. It is essential for these countries to create favorable conditions for developing core capacities and building an ecosystem for AI innovation. Recommendations include:

- Expanding educational and research capacities through targeted investments in technical universities, research institutions and doctoral programs focused on AI, data science and machine learning (Chaudhuri et al., 2022).
- Supporting small and medium-sized enterprises (SMEs) in integrating AI solutions, through subsidies, public calls, tax incentives and shared technology centers.
- Developing digital infrastructure such as high-speed networks, data storage and computing capacity, which are essential prerequisites for AI computing (Tanantong & Wongras, 2024).
- Ensuring international technology transfer and supporting cross-border projects that enable the sharing of know-how and reduce the innovation gap.

5. Conclusion

These recommendations reflect the need for an asymmetric but coordinated AI policy at the European Union level. The development of artificial intelligence cannot be addressed with a single approach – it requires respect for different stages of development, as well as taking into account the social, economic and institutional contexts of individual countries. The implementation of these strategies could significantly contribute to balanced and inclusive technological development within the EU. AI has the potential to make a fundamental contribution to solving the biggest global challenges, if deployed responsibly, inclusively and ethically. The future of AI will not be defined only by technical capabilities, but also by our ability to integrate these technologies into society in a way that respects human values and rights.

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The impact of the use of renewable energy sources on the energy self-sufficiency of EU countries

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Abstract: This study explores the relationship between the use of renewable energy sources (RES), energy self-sufficiency, and economic performance across European Union (EU) member states. In the context of growing environmental challenges, energy dependency, and the transition to a low-carbon economy, investments in RES are increasingly viewed as a strategic tool to enhance energy sustainability. The analysis draws on 2022 Eurostat data from 27 EU countries and employs descriptive statistics, correlation analysis, and linear regression to test two hypotheses: first, that a higher share of RES is positively associated with greater energy self-sufficiency; and second, that higher GDP per capita is linked to increased adoption of RES. The results support the first hypothesis, revealing a statistically significant and positive correlation between the share of RES and energy self-sufficiency ($R^2 = 0.2287$; $p = 0.0116$). However, the second hypothesis was not supported, as no statistically significant relationship was found between GDP per capita and the share of RES ($R^2 = 0.0020$; $p = 0.8203$). These findings suggest that while RES investments play a meaningful role in reducing energy dependence, economic output alone does not reliably predict the degree of renewable energy integration. The study highlights the importance of tailored policies that reflect national conditions to promote effective energy transitions across the EU.

Keywords: energy self-sufficiency, renewable energy sources

Introduction

The global economy is currently facing growing challenges in the areas of sustainability, climate change and energy security. These challenges require effective solutions aimed at reducing the environmental impact of economic growth. One of the key approaches to achieving this goal is to increase energy efficiency, i.e. the ability to produce higher economic value with lower energy consumption. Energy efficiency is therefore considered one of the main indicators of sustainable development and at the same time a means of reducing greenhouse gas emissions. One of the tools that can contribute to improving energy efficiency is investment in renewable energy sources, such as solar, wind or geothermal technologies. These technologies not only reduce dependence on fossil fuels, but can also positively affect the efficiency of energy use within the economy. The aim of this article is therefore to examine the relationship between investment in renewable energy sources and improving energy efficiency. Using regression analysis, we will attempt to determine the relationship between the rate of use of renewable energy sources and the level of energy self-sufficiency, which can be a valuable basis for the creation of environmental and energy policies at both the national and international levels.

1. Literature Review

Increasing energy self-sufficiency has become one of the main priorities of the European Union (EU) energy policy in recent decades, especially in the context of geopolitical risks, climate change and the unsustainable use of fossil fuels. One of the main tools for achieving greater energy independence and security is the development of renewable energy sources (RES). Energy self-sufficiency is a key factor in the transition to a low-carbon economy and is often considered the "first fuel link" of sustainable development. Its increase not only allows for a reduction in environmental burden, but also supports economic growth through energy savings and higher productivity (Costantini & Martini, 2010). Increasing the use of renewable energy sources is one of the main ways to use natural resources more efficiently, reduce environmental burden, reduce greenhouse gas emissions and at the same time strengthen energy security and countries' independence from external energy suppliers. This trend is also a key element in meeting the EU's climate goals and transitioning to a low-carbon economy. The key EU strategic document that forms the framework for the transition to sustainable energy is the European Green Deal (2019), which declares the goal of achieving climate neutrality by 2050. This document explicitly supports the more intensive use of renewable sources as a tool not only for environmental but also for geopolitical stabilization (European Commission, 2019). At the academic level, the relationship between energy security and the development of renewable sources has been analyzed in detail, for example, in the study by Sovacool (2009), which states that investments in domestic energy production from RES lead to a long-term reduction in energy dependence. The author also points out that energy self-sufficiency is not only a technical but also a political concept, conditioned by the institutional and regulatory frameworks of individual countries. According to research by Polzin et al. (2015), both public and private investments in RES stimulate technological innovations that lead to more efficient energy production and consumption. Some studies empirically confirm the positive relationship between investments in renewables and increased energy efficiency. For example, Wang et al. (2020) analyzed panel data from 30 countries and found that higher investments in solar and wind energy lead to significant improvements in energy performance. Similarly, the work of Zafar et al. (2019) shows that the transition to renewables has a strong positive impact on energy efficiency, especially in developing economies. The empirical link between economic growth and RES development in the context of EU countries is examined by Menegaki (2011), who uses panel data and a random effects model. The results suggest that there is a positive, although not always causal, link between GDP growth and investments in renewable technologies. This study also highlights that the economic conditions of individual countries significantly affect the ability to implement green policies. The literature suggests that investments in renewable energy sources can significantly contribute to increasing the energy self-sufficiency of EU countries, but their effectiveness depends on a combination of technical, economic and regulatory factors. In this context, it is important to take into account the different starting conditions of individual Member States and their approach to energy planning.

2. Methodology

The aim of this study is to analyse the level achieved in the Member States of the European Union in terms of energy self-sufficiency, the use of renewable energy sources (RES) and the level of economic performance in the Member States of the European Union. The research aims to verify two hypotheses:

H1: There is a positive correlation between the rate of energy self-sufficiency and the share of renewable energy sources (RES) in EU Member States.

H2: Countries with higher economic performance (GDP per capita) achieve a higher share of RES than countries with lower GDP per capita.

The research sample consists of 27 Member States of the European Union (as of 2022). We will use quantitative research focusing on descriptive statistics, correlation analysis and regression analysis. The aim is to verify the existence and strength of relationships between variables at the level of EU Member States. The data source will be Eurostat (energy statistics, GDP per capita), the most recent available harmonised year is 2022. We will use simple linear regression at a statistical significance level of α = 0.05. Gross domestic product (GDP) is a measure of economic activity and is commonly used as a proxy for changes in the material standard of living of a country. It refers to the value of the total final output of goods and services produced by the economy in a certain period of time. Real GDP per capita is calculated as the ratio of real GDP (GDP adjusted for inflation) to the average population in a particular year and is based on rounded figures. In our research, we set real GDP per capita as the independent variable.

Energy self-sufficiency is calculated using the following ratio:

• numerator: primary production + recovered and recycled products

• denominator: primary production + recovered and recycled products + imports + stock depletion

The resulting calculations are expressed in percentages and rounded to 2 decimal places.

The renewable energy share (RES) measures the share of energy consumption from renewable sources in gross final energy consumption according to the Renewable Energy Directive. Gross final energy consumption is the energy consumed by end-users (final energy consumption) plus network losses and self-consumption of power plants.

3. Results

The European Union is currently facing unprecedented energy policy challenges, exacerbated by global environmental crises, geopolitical instability and growing demands for sustainability. Reducing dependence on fossil fuel imports and transitioning to a low-carbon economy are key priorities for Member States. In this context, the relationship between energy self-sufficiency, the share of renewable energy sources (RES) and the economic performance of individual countries is increasingly being discussed (Ahmed et al., 2024; Gaweda et al., 2025). Several studies (Di Silvestre et al., 2021; Lux et al., 2024) point out that energy self-sufficiency is not only a question of technical infrastructure and the availability of natural resources, but is closely related to the investment opportunities, regulatory environment and macroeconomic stability of the country. At the same time, there is growing evidence that a higher share of RES can significantly contribute to strengthening energy independence, with individual EU regions showing significant differences in the adoption rate of renewable technologies (Marks-Bielska et al., 2020; Jasinski et al., 2024).

From a geographical perspective, Nordic and Alpine countries appear to achieve above-average RES shares compared to Central and Southern European countries, which may be a consequence not only of natural potential, but also of long-term policies and investment strategies (Mucha-Kus et al., 2021; Hansen et al., 2019). Similarly, Mazur et al. (2023) and Tutak & Brodny (2022) highlight the importance of GDP per capita as a predictor of success in implementing green technologies. More advanced economies are able to allocate a larger volume of public and private resources to the energy transformation, thereby accelerating their transition to renewable sources.

Research by Balezentis et al. (2022), Rqiq et al. (2024) and Wolters & Brusselaers (2024) also points to the need to create analytical frameworks that take into account not only technological but also socio-economic variables. The aim of this study is therefore to quantitatively analyze the relationship between the level of energy self-sufficiency, the share of RES and GDP per capita in EU Member States, assuming the existence of a positive correlation between the monitored variables (Fresia et al., 2024; Magdziarczyk et al., 2024).

Table 1. EU countries according to energy self-sufficiency and use of renewable energy sources in 2022.

	Country	Renewable energy sources %	Energy self-sufficiency %	Level achieved
1.	**Sweden**	66,287	52,60	high self-sufficiency & high share of renewable energy sources (RES)
2.	**Estonia**	38,542	62,11	high self-sufficiency & growing RES
3.	**Romania**	24,229	57,02	high self-sufficiency & low RES
4.	**Czechia**	18,123	51,33	high self-sufficiency & low of RES
5.	**Bulgaria**	19,044	50,59	high self-sufficiency & low RES
6.	**Latvia**	43,720	43,38	medium self-sufficiency & high RES
7.	**Finland**	47,740	46,97	medium self-sufficiency & high RES
8.	**Denmark**	42,383	36,21	medium self-sufficiency & high RES
9.	**Austria**	34,075	30,02	medium self-sufficiency & growing RES
10.	**Croatia**	28,088	29,54	medium self-sufficiency & growing RES
11.	**Poland**	16,629	48,10	medium self-sufficiency & low RES
12.	**France**	20,445	42,54	medium self-sufficiency & low RES
13.	**Hungary**	15,128	34,35	medium self-sufficiency & low RES
14.	**Slovenia**	25,002	31,53	medium self-sufficiency & growing RES
15.	**Germany**	20,814	29,55	medium self-sufficiency & low RES
16.	**Slovakia**	17,481	29,23	medium self-sufficiency & low RES
17.	**Portugal**	34,675	23,69	low self-sufficiency & growing RES
18.	**Spain**	21,896	22,08	low self-sufficiency & low RES
19.	**Ireland**	13,068	19,03	low self-sufficiency & low RES

20.	**Lithuania**	29,599	12,58	low self-sufficiency & growing RES
21.	**Italy**	19,131	18,35	low self-sufficiency & low RES
22.	**Belgium**	13,816	16,26	low self-sufficiency & low RES
23.	**Netherlands**	15,134	11,64	low self-sufficiency & low RES
24.	**Greece**	22,671	12,30	low self-sufficiency & low RES
25.	**Cyprus**	19,427	9,09	low self-sufficiency & low RES
26.	**Luxembourg**	14,262	8,15	low self-sufficiency & low RES
27.	**Malta**	13,969	1,57	low self-sufficiency & low RES

Source: Eurostat. (2025)

From the perspective of energy policy and climate goals of the European Union, it is crucial to monitor the level of energy self-sufficiency of individual Member States and their progress in the use of renewable energy sources (RES). Based on the combination of these two indicators, EU countries can be divided into four basic categories, each of which represents a different stage of development in the context of the energy transition.

High energy self-sufficiency and high share of RES. This group includes countries that achieve an above-average level of energy self-sufficiency (i.e. they cover a significant part of their energy consumption from domestic sources) and at the same time have an established renewable energy sector. An example is Sweden, which achieves more than 66% share of RES and more than 52% energy self-sufficiency. Its model based on the use of hydropower, biomass and wind energy represents a benchmark for other Member States.

High energy self-sufficiency and low or increasing share of RES. This category includes countries that demonstrate a high degree of self-sufficiency, but their energy mix is still significantly dependent on non-renewable sources. Estonia, for example, has achieved self-sufficiency at 62%, but the share of RES is still lower (38.5%), although it shows an increasing trend. Similarly, Romania, the Czech Republic and Bulgaria have above-average self-sufficiency, but their share of RES remains below the European average.

Medium energy self-sufficiency and high or increasing share of RES. This group includes countries that are not fully energy self-sufficient, but are actively developing renewable energy sectors. An example is Finland with almost 48% share of RES and self-sufficiency just below 47%. Similarly, Denmark, Latvia and Austria have shown significant progress, especially in the field of wind and hydropower. These countries form a dynamic group that has the potential to move into the first category.

Low energy self-sufficiency and low share of RES. The most vulnerable group in terms of energy security are countries that are heavily dependent on energy imports and have limited development of renewable sources. Typical examples include Malta (with self-sufficiency at 1.6%), Cyprus, Luxembourg and Ireland. These countries face challenges such as geographical isolation, insufficient infrastructure or limited natural potential for the development of RES. Their situation requires more targeted support from the EU, as well as significant investments in innovation and diversification of sources.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0,4782177
R Square	0,2286922
Adjusted R Square	0,1978398
Standard Error	15,082369
Observations	27

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1686,175116	1686,175	7,41248	0,011632839
Residual	25	5686,946514	227,4779		
Total	26	7373,12163			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	14,562675	6,610880356	2,202834	0,037045	0,947312132	28,178038	0,947312132	28,178038
Renewable energy sources	0,6278855	0,230620916	2,722587	0,011633	0,152912846	1,1028582	0,152912846	1,1028582

Figure 1. Output of regression and correlation analysis for energy self-reliance and renewable energy sources
Source: Own processing according to Eurostat.

Regression analysis aimed at examining the relationship between the share of renewable energy sources and the rate of energy self-sufficiency in the countries of the European Union yielded statistically significant results that support the hypothesis of the existence of a positive association between the analyzed variables shown in Fig. 1. The value of the coefficient of determination $R^2 = 0.2287$ indicates that approximately 22.9% of the variability in the rate of energy self-sufficiency can be explained by changes in the share of renewable energy sources. Although this is a modest explanation of the variability, it is considered relevant from a methodological point of view, especially when analyzing socio-economic data with a high degree of complexity. The adjusted coefficient of determination (Adjusted $R^2 = 0.1978$) also confirms that the model maintains an acceptable level of explanatory power even after taking into account the number of variables used.

In terms of the overall significance of the model, the ANOVA test result shows a Significance F value of = 0.0116, which is significantly lower than the standard significance level ($\alpha = 0.05$). This means that there is a statistically significant linear relationship between the share of renewable energy sources and the rate of energy self-sufficiency, and that the regression model as a whole is statistically significant. The individual regression coefficient for the variable "Renewable energy sources" reaches a value of 0.6279, which indicates that every 1% point increase in the share of renewable energy sources is associated with an increase in the rate of energy self-sufficiency by 0.63 units. This coefficient is also statistically significant ($p = 0.0116$) and its 95% confidence interval (0.153 – 1.103) does not contain zero, which supports the credibility of the positive relationship. The constant (intercept) of the model, representing the expected value of energy self-sufficiency at zero RES share, takes the value 14.56 and is also statistically significant ($p = 0.0370$), although its interpretative significance is secondary to the research focus. In conclusion, it can be stated that the regression analysis has provided convincing evidence of a positive and statistically significant relationship between the rate of use of renewable energy sources and the level of energy self-sufficiency. These results support the proposed hypothesis 1 and suggest that investments in RES can be an effective tool for strengthening the independence of EU countries from external energy supplies.

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0,0449662							
R Square	0,00202196							
Adjusted R Square	-0,0363618							
Standard Error	24906,4721							
Observations	28							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	32677521,11	32677521	0,052677	0,820264138			
Residual	26	16128641222	6,2E+08					
Total	27	16161318743						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	39889,4999	10839,05446	3,680164	0,00107	17609,50432	62169,495	17609,504	62169,4954
Renewable energy sources	-87,336932	380,5271032	-0,22952	0,820264	-869,5215946	694,84773	-869,52159	694,847731

Figure 2. Output of regression and correlation analysis for GDP and renewable energy sources
Source: Own processing according to Eurostat.

Based on the regression analysis focused on the relationship between the share of renewable energy sources and the amount of gross domestic product (GDP) in the countries of the European Union, it can be stated that the results do not support the hypothesis of a positive relationship between these variables Fig. 2. The value of the coefficient of determination (R^2) reached the level of 0.002, which means that the share of renewable energy sources explains only 0.2% of the variability in GDP. This result points to an extremely low explanatory power of the model, while the negative value of the adjusted coefficient of determination (Adjusted $R^2 = -0.0364$) indicates that the model, after taking into account the number of variables, practically explains no variability of the dependent variable and its predictive value is weak. From the point of view of the statistical significance of the model as a whole, it is not possible to confirm the existence of a significant relationship between the variables under study. The Significance F value in the ANOVA test is 0.8203, which is well above the standard significance level of 0.05, and we therefore reject the alternative hypothesis of a statistically significant linear relationship. The regression coefficient for the variable "Renewable energy sources %" is -87.34, which would indicate that each percentage point increase in the share of renewable sources would be associated with a decrease in GDP by 87.34 units. However, this relationship is not statistically significant ($p = 0.8203$) and the confidence interval (95%) ranges from -869.52 to +694.85, which means that the actual impact can move in both directions – positive and negative. The intercept, which represents the expected level of GDP at zero share of RES, was statistically significant ($p = 0.0011$), but its significance from the point of view of the research question is limited.

Overall, the regression analysis did not provide sufficient evidence to support hypothesis 2 that there is a statistically significant relationship between the rate of renewable energy use and GDP in the analyzed set of countries. The results indicate the need to supplement the analysis with additional variables, or possibly more sophisticated models, which could better capture the complexity of the relationship between economic development and energy factors.

4. Discussion

The findings of this study point to the important role of renewable energy sources (RES) in increasing the energy self-sufficiency of the European Union Member States. The results are in line with previous empirical studies (e.g. Sovacool, 2009; Del Río & Mir-Artigues, 2014), which point to the positive impact of investments in RES on reducing dependence on external energy sources. The positive correlation found between the share of RES and the level of energy self-sufficiency can also be attributed to the increasing availability of technologies, support from EU policies and the diversification of energy mixes in several countries. On the other hand, the results of the regression analysis did not confirm a statistically significant relationship between the share of RES and the level of GDP, which is in slight contradiction with some studies indicating a positive impact of green energy on economic growth (e.g.

Menegaki, 2011). A possible explanation for this finding is that the economic performance of countries is influenced by a wide range of factors, with the share of RES itself being only one of many determinants. In addition, some countries with a high share of RES (e.g. the Nordic countries) may have specific structural and geographical assumptions that are not directly transferable to other Member States. Another important aspect to consider is the time lag with which the economic benefits of investments in RES manifest themselves. The economic effects of these investments may be long-term and indirectly mediated through job creation, technological progress or an improvement in the trade balance due to lower fuel imports. In this context, it would be appropriate to apply multifactor models or panel data with a time dimension in future research, which would allow for a more precise identification of causal relationships. Another limitation of this study is the relatively small number of observations and the absence of control for other socio-economic variables, such as infrastructure investment, industrialization rates, or regulatory frameworks. Taking these variables into account could contribute to a more precise understanding of the relationships between RES, energy self-sufficiency, and economic performance.

5. Conclusion

Based on the results of the analysis, it can be concluded that the study confirmed a positive and statistically significant relationship between the use of renewable energy sources and the energy self-sufficiency of EU countries, thus supporting hypothesis 1. On the contrary, hypothesis 2 on the connection between the share of RES and the level of GDP was not confirmed, which points to the need to expand the model with additional variables to better capture the complex relationship between energy and economic performance. An analysis of the distribution of EU countries according to energy self-sufficiency and the use of RES reveals significant differences in their approach to energy transformation. Countries such as Sweden, Finland and Denmark are leaders in green technologies, while several smaller and southern states face serious challenges. These differences indicate the need for differentiated policies within the EU that will reflect national specificities and enable an effective and fair energy transformation at the pan-European level.

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Prospects for sustainable sector interconnection in the era of green transformation

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Abstract: This study analyses the relationships between the number of people working in creative professions, public expenditure on culture and recreation as (% of GDP), the share of renewable energy sources, and energy self-sufficiency of selected European countries. Based on correlation and multiple regression analysis, it was found that renewable energy sources have a statistically significant positive impact on the level of energy self-sufficiency. The other analyzed variables (public expenditure on culture and recreation and the number of people employed in the creative industry) were not confirmed as significant factors. The results support the importance of the strategic development of renewable energies as a tool for increasing the energy independence of countries. The study also compares GDP from culture and recreation per capita in the cultural and creative industries in Slovakia and the Czech Republic and employment in the cultural and creative industries sector as a significant indicator.

Keywords: creative industries; energy self-reliance, general government expenditure on recreation, culture and religion, renewable energy sources; share of persons working as creative

Introduction

In the context of growing challenges related to climate change, energy security and pressure for sustainable development, the need for an ecologically responsible and at the same time economically viable approach across all sectors is increasingly emphasized (Bina, 2013). The creative industry, including areas such as design, visual arts, cultural events, film, music and digital creation, is no exception. Given its high degree of flexibility, innovative potential and ability to influence social values, it represents an ideal platform for applying the principles of economic self-sufficiency and the use of renewable energy sources (RES) (Boorová, 2021). The application of solar, wind, hydropower or biomass within the creative industry allows the creation of energy-independent and ecologically sustainable production spaces, cultural centers or events and the provision of their basic needs independently of external suppliers (Curtis, Reid & Ballard, 2012).

In the context of the current climate crisis and the growing demands for the decarbonization of the economy, the energy sector is also facing pressure for innovation and social acceptance of transformational changes. Therefore, it is necessary to explore the potential connections between the creative industries and the energy sector, especially in terms of their contribution to a sustainable energy transition. This article uses an interdisciplinary approach that combines knowledge from the fields of cultural policy, environmental communication and innovation studies. The aim is to show how cultural and creative industries can play an active role in energy literacy, public participation, as well as in the design of solutions that are socially inclusive and technologically innovative. In the analytical part of the paper, we compare the relationships between selected indicators as well as GDP from culture and recreation in the Czech and Slovak Republics, employment in the creative industry, and recommend a more systematic integration of creative actors into the planning and implementation of energy projects, as well as the creation of cross-sectoral platforms at the level of cities and regions. According to Hawkes (2021), the systematic integration of creative actors into the planning and implementation of energy projects, as well as in the creation of cross-sectoral platforms at the city and regional level, is important.

1. Literature Review

Currently, the climate crisis and the need to transition to sustainable economic models are becoming a priority not only in the field of industry or transport, but also in the cultural and creative sectors. As Sachs (2015) states, achieving the Sustainable Development Goals requires a comprehensive approach that links economic, environmental and social dimensions. The creative industries, defined according to UNCTAD (2010) as a sector combining creativity, production and commercialization of creative content, have significant potential to contribute to these goals precisely thanks to their ability to shape values and influence public behavior.

The flexibility and innovativeness of the creative industries make them ideal candidates for implementing sustainable solutions, including the use of renewable energy sources. According to Florida (2002), creative professionals play an important role in urban development and innovation, and can support ecological transformation through artistic intervention and technological creativity. This view is also developed by Hawkes (2001) and Holden (2006), who draw attention to the importance of the cultural dimension of sustainability as the fourth pillar of sustainable development.

Social acceptance of energy transformations often depends on effective environmental communication and public participation (Nisbet & Scheufele, 2009). In this context, the creative industries play an important role as a mediator between technical solutions and the public, while arts and culture can communicate complex climate and energy issues in a comprehensible and emotionally powerful way (Curtis et al., 2012). Furthermore, according to Bina's analysis (2013), cross-sectoral cooperation is key to overcoming sectoral barriers in the energy transformation process.

Green festivals, energy-self-sufficient cultural centres and initiatives such as Creative Carbon Scotland demonstrate that sustainability in the cultural sector is not just a theoretical possibility, but increasingly a practical reality (Julie's Bicycle, 2020). These initiatives show that the creative sector can be not only a consumer but also a producer of energy, especially through renewable sources such as solar or wind energy (Prendergast & Foley, 2020). Creative sectors have the potential not only to implement green technologies, but also to popularise and communicate them to the general public through cultural products and experiences. Examples include art installations powered by solar energy, music festivals with a low carbon footprint, film productions using green studios, or fashion brands that not only use ecological materials but also renewable energy throughout the production cycle. The introduction of renewable energy sources within creative projects also opens up opportunities for reducing operating costs and increasing economic independence of entities. Energy self-sufficiency can also be part of "green branding", thereby increasing competitive advantage and attractiveness for environmentally conscious consumers. This creates hybrid business models that combine economic profitability with ecological and social responsibility (Prendergast & Foley, 2020).

2. Methodology

Linking public spending on culture and recreation as (% of GDP) and employment in the creative industries with energy can provide an interesting insight into the relationship between innovation, technological development, sustainability and economic performance. The analysis uses data from the Eurostat database. The research focuses on identifying the relationships between the share of people working in creative professions, the share of renewable energy sources, the share of public spending on culture and recreation as (% of GDP), and the level of energy self-sufficiency in European countries. The variables included in the statistical processing are: General government expenditure on culture and recreation as (% of GDP), the % of people employed in the creative industries, the share of renewable sources in EU countries in % and energy self-sufficiency in %. Based on the studied professional literature, research hypotheses were formulated, which are based on theoretical knowledge and previous empirical studies.

H_1: There is a statistically significant positive relationship between the number of people working in creative professions and the share of renewable resources in EU countries.

H2: There is a statistically significant relationship between the amount of General government expenditure on culture and recreation as (% of GDP) and the share of people working in creative professions.

To test these hypotheses, a correlation analysis was used based on the calculation of Pearson correlation coefficients, which quantify the strength and direction of the linear relationship between individual variables. The analysis was performed on data available from the statistical databases of Eurostat and OECD. The values of the coefficients r were interpreted according to the standard classification (weak: $|r| < 0.3$; medium: $0.3 \leq |r| < 0.6$; strong: $|r| \geq 0.6$). Subsequently, a regression model was created for each hypothesis to assess the causal relationships between the independent variables (share of renewable resources, share of creative workers, General government expenditure on culture and recreation as (% of GDP) and the dependent variable (energy self-sufficiency).

3. Results

The aim of the correlation analysis was to examine the relationships between the selected variables: share of renewable energy sources (%), general government expenditure on culture and recreation as (% of GDP), share of people working in creative professions and energy self-sufficiency (%). The Pearson-type correlation coefficient was used to quantify linear relationships between the variables.

Table 1: Results of the correlation analysis Renewable energy sources %, General government expenditure on culture and recreation as (% of GDP), Share of persons working as creative, Energy self-reliance % from EU countries data for 2022

	Renewable energy sources %	General government expenditure	Persons working as creative	Energy self-reliance %
Renewable energy sources %	1			
General government expenditure	-0,04555	1		
Share of persons working as creative	-0,13121	0,06771	1	
Energy self-reliance %	0,478218	-0,33017	0,228029	1

Source: Own processing based on data from the Eurostat database

The results of the correlation matrix provide insight into the strength and direction of the linear relationships between these variables. The strongest observed relationship was between the share of renewable energy sources and energy self-sufficiency ($r = 0.478$), which represents a moderately strong positive correlation. This result indicates that countries with a higher share of renewable energy sources in the energy mix tend to show a higher level of energy independence. This relationship can be interpreted as evidence that the support of renewable technologies contributes to the stabilization of national energy systems and the reduction of dependence on imported energy commodities. This result supports the hypothesis that the development of renewable technologies contributes to the reduction of energy dependence on external suppliers. Conversely, a moderate negative correlation was identified between general government expenditure on culture and recreation as (% of GDP) and energy self-sufficiency ($r = –0.330$). This result may indicate that economically more advanced countries, often with higher consumption and industrialization, are also more dependent on external supplies and imports of energy. This phenomenon may be related to high industrial consumption and low domestic potential for energy production from own resources. Alternatively, it may be a consequence of globalized energy markets and lack of domestic energy resources. The relationships between the other variables were weak to negligible.

The correlation between renewable energy sources and general government expenditure on culture and recreation as (% of GDP) was ($r = –0.046$) and between renewable energy sources and the share of creative workers ($r = -0.131$) suggest that a country's economic performance and creative potential are not directly linked to the level of renewable energy use. As the share of creative workers increases, the second variable tends to decrease slightly. Similarly, the correlation between general government expenditure on culture and recreation as (% of GDP) and creative professions ($r = 0.068$) is low, which contradicts the common assumption that higher general government expenditure on culture and recreation as (% of GDP) is related to the development of the creative sector. This suggests that the share of renewable energy in the economy may not be directly influenced by either the performance of the economy or the structure of employment in the creative industry. Consider this relationship to be negligible or insignificant. An interesting, albeit weak, positive relationship (r = 0.228) was observed between the share of creative workers and the level of energy self-sufficiency. This relationship may indicate that companies with greater innovative and creative potential are more effective in implementing technologies to ensure their own energy stability. Although the correlation coefficient is low, it points to a possible connection between cultural capital and sustainability, which may reflect the innovative potential and higher rate of adaptation of new technologies in companies with a developed creative sector. Detailed results are presented in Table 1.

Overall, it can be stated that the most significant factor related to energy self-sufficiency is the share of renewable energy sources, while the other variables do not show strong correlations. These findings represent a starting point for further quantitative analysis (e.g. regression modeling) that could identify causal relationships and control for intervening variables.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0,56922
R Square	0,32401
Adjusted R Square	0,23583
Standard Error	14,72085
Observations	27

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	2388,940	796,3133	3,67467	0,02684
Residual	23	4984,182	216,7035		
Total	26	7373,122			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	22,83353	8,74929	2,60976	0,0157	4,73424	40,9328	4,73424	40,93283
Renewable energy sources %	0,60694	0,25386	2,39088	0,0254	0,08180	1,1321	0,08180	1,13208
% GDP	-0,00021	0,00016	-1,30386	0,2052	-0,00055	0,0001	-0,00055	0,00012
% pearsons as creative in 2022	0,53546	25,42537	0,02106	0,9834	-52,06092	53,1318	-52,06092	53,13183

Figure 1. Multiple linear regression of EU country data: Renewable energy sources %, general government expenditure on culture and recreation as (% of GDP), Persons working as creative, Energy self-reliance % for 2022

Source: Own processing based on data from the Eurostat database

The aim of the multiple linear regression was to examine the extent to which the share of renewable energy sources, general government expenditure on culture and recreation as (% of GDP) and the number of people working in creative professions can predict the level of energy self-sufficiency of countries. Multiple R = 0.569 explains the correlation between the predicted and actual values of the dependent variable, which indicates a moderately strong relationship between the predictors and energy self-sufficiency. R Square = 0.324 is the coefficient of determination and shows that 32.4% of the variability in the level of energy self-sufficiency can be explained by the variation in the three independent variables. The remaining 67.6% of the variation remains unexplained, which may indicate the existence of other significant factors. Adjusted R Square = 0.235 explains the correction of the coefficient of determination for the number of predictors and indicates that after taking into account the size of the model, it explains 23.5% of the variability. Significance F = 0.027. The result of the ANOVA test is statistically significant at the $\alpha = 0.05$ level, which means that the overall model is significant and at least one of the predictors has a statistically significant effect on the dependent variable. Renewable energy sources ($p = 0.0254$). This variable has a positive and statistically significant effect on energy self-sufficiency. The coefficient 0.607 means that an increase in the share of renewable energy sources by 1 percentage point will increase energy self-sufficiency by 0.607 percentage points on average, all other things being equal. general government expenditure on culture and recreation as (% of GDP) and the share of creative workers. Both variables are statistically significant at the $\alpha = 0.05$ level ($p > 0.1$), which indicates that in this model their contribution to explaining the variability of energy self-sufficiency is sufficiently convincing. The results of the regression analysis confirm the significant positive effect of the share of renewable energy sources on energy self-sufficiency. This relationship was also identified in the correlation analysis and is further supported by statistical significance within the regression model. The other variables (general government expenditure on culture and recreation as (% of GDP), creative workers) do not make a significant contribution in this model, which may be a consequence of the limited sample (n = 27) or their indirect effects.

To confirm or refute hypothesis 2: There is a statistically significant relationship between the level of general government expenditure on culture and recreation as (% of GDP) and the share of people working in creative professions, we performed a multiple linear regression of EU country data on general government expenditure on culture and recreation as (% of GDP) for the years 2014-2023 and the share of people employed in the creative industry. The results of the regression analysis are presented in Figure 2.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0,52834
R Square	0,27915
Adjusted R Square	-0,14488
Standard Error	0,20978
Observations	28,00000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	10	0,28972	0,02897	0,65832	0,74650
Residual	17	0,74816	0,04401		
Total	27	1,03788			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95,0%*	*Upper 95,0%*
Intercept	0,23932	0,15986	1,4970	0,15272	-0,09796	0,57661	-0,09796	0,57661
2014	0,08475	0,56126	0,1510	0,88176	-1,09941	1,26890	-1,09941	1,26890
2015	-0,37488	0,73473	-0,5102	0,61646	-1,92503	1,17527	-1,92503	1,17527
2016	0,88620	0,71077	1,2468	0,22937	-0,61340	2,38579	-0,61340	2,38579
2017	-0,43620	0,66263	-0,6583	0,51917	-1,83424	0,96183	-1,83424	0,96183
2018	0,50297	0,67902	0,7407	0,46897	-0,92964	1,93557	-0,92964	1,93557
2019	-0,15789	0,65821	-0,2399	0,81329	-1,54659	1,23081	-1,54659	1,23081
2020	-0,77463	0,46158	-1,6782	0,11160	-1,74848	0,19923	-1,74848	0,19923
2021	0,65287	0,68683	0,9505	0,35515	-0,79622	2,10196	-0,79622	2,10196
2022	-0,48968	0,58682	-0,8345	0,41559	-1,72776	0,74839	-1,72776	0,74839
2023	0,29260	0,53981	0,5420	0,59482	-0,84631	1,43151	-0,84631	1,43151

Figure 2. Multiple linear regression of general government expenditure on culture and recreation as (% of GDP) and the share of people employed in the creative industries of EU countries

Source: Own processing based on data from the Eurostat database

Linear multiple regression provided the following results: $R^2 = 0.279$, the p-value of the regression coefficient is detailed in Figure 2 for individual years 2014–2023. These values mean that the explanatory power of the model is minimal and it is not possible to confirm the existence of a linear relationship between the variables. The expectations of a positive impact of general government expenditure on culture and recreation as (% of GDP) on employment in the creative sector were not confirmed in this analysis. Employment in the creative industry may be more influenced by market demand and digital trends than by the volume of public finances, year-on-year fluctuations or crisis periods (e.g. the COVID-19 pandemic) may have contributed to the deformation of the data structure. Based on the analysis of data from 2014–2023 for EU countries, it can be concluded that there is no statistically significant positive correlation between general government expenditure on culture and recreation as (% of GDP) and employment in the creative industry.

3.1. Comparison of selected indicators of Slovakia and the Czech Republic in the creative industry

Cultural and creative industries represent an important part of the national economy, and their economic benefits are reflected not only in direct but also indirect effects. Direct economic effects include the creation of added value, employment of the economically active population, as well as trade activities associated with the export and import of cultural goods. These activities are quantified within the statistics of the Cultural and Creative Industries Satellite Account, which provides important data on the economic performance of this sector. Indirect impacts of cultural and creative industries go beyond the sector itself. Creative production often generates significant demand in other economic areas, especially in the tourism sector. Cultural and creative outputs play the role of inputs into a wide range of economic activities - from content for media and digital platforms, through innovation potential in industry, to the development of human capital through specialized skills, expertise and intellectual property. Despite the increasing recognition of the importance of cultural and creative industries, their economic contribution remains often underestimated in public policies. This is partly due to the lack of a uniform methodology at the international level – the sectoral breakdown and classification of individual components of cultural and creative industries differ significantly between countries. This heterogeneity complicates the possibility of comparing data across countries. Despite these limitations, the Slovak satellite account data are well comparable with the Czech Republic. Although there are some methodological differences (e.g. in the Czech Republic, travel agency services are also included in the cultural heritage area), this is the closest available comparative framework for Slovakia. Comparing Slovakia and the Czech Republic is an analytically meaningful approach, as these are two countries with similar historical, cultural and institutional developments. Both countries were part of a common state entity until 1993 and, after the division, they retained many parallels in public administration, economic structure and political priorities. Thanks to this comparability, it is possible to identify differences and similarities in approaches to financing selected areas of public policy – in this case, spending on recreation, culture and religion – and evaluate them in the context of different macroeconomic conditions, size of the economy or population base. Moreover, both countries are members of the European Union and are subject to the same methodological standards of Eurostat (e.g. COFOG classification), which allows for a direct and reliable comparison of statistical indicators. Such a comparative approach helps to better understand how public institutions respond to social needs and what space in national budgets the cultural and recreational sphere occupies in different economic and political contexts.

In 2019, **the cultural and creative industries sector accounted for 1.7% of the GDP** of the Slovak economy. Between 2017 and 2019, the absolute value of production in this sector increased from EUR 1.39 billion to EUR 1.60 billion, representing an increase of EUR 206 million, or EUR 37 per capita. Comparable data from the Czech Republic for 2020 indicate a share of the cultural and creative industries at 1.56% of GDP, corresponding to production of EUR 3.55 billion. However, in the period 2017-2019, there was much more dynamic growth there, with the recorded absolute increase representing EUR 892 million, which is an increase of EUR 83 per capita. These data point to the potential of the cultural and creative industries as a growth segment of the national economy, with its impact going beyond the sector itself and playing a significant role in supporting innovation, regional development and employment in the broader economic environment.

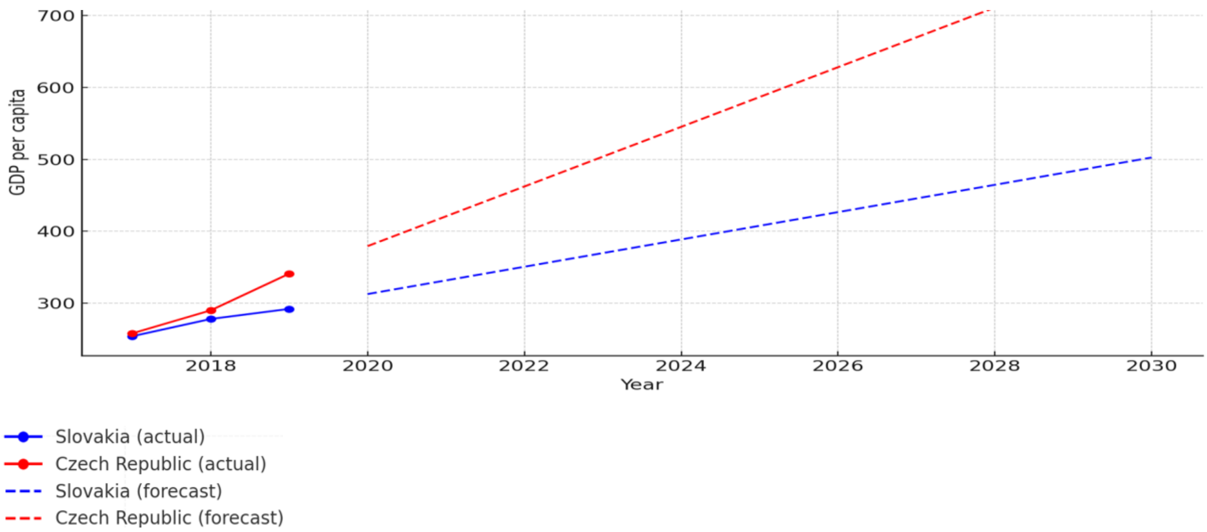

Figure 3. Development of GDP in the field of culture and creative industries per capita in Slovakia and the Czech Republic, in 2017-2019 and projected GDP development until 2030 in euros p. c.

Source: Own processing according to www.strategiakultury.sk

Figure 3 shows historical data (2017-2019) and shows that both countries have experienced stable growth. However, the Czech Republic’s growth between 2018 and 2019 was significantly stronger. The forecast (2020-2030) suggests that: The Czech Republic is expected to maintain a stronger growth trend, potentially reaching almost EUR 800 per capita by 2030. Slovakia is expected to grow at a more moderate pace, reaching around EUR 500 per capita by 2030. Widening gap: The gap in GDP per capita between the two countries is expected to widen over time, indicating a more dynamic development of cultural and creative industries in the Czech Republic.

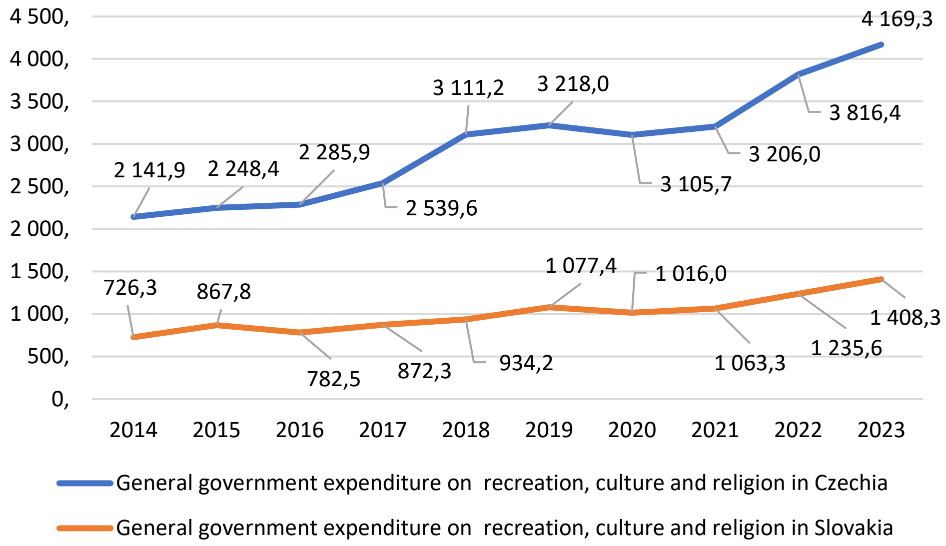

Figure 4. General government expenditure on culture and recreation in mil. euro in Czechia and Slovakia during period 2014 - 2023

Source: Own processing based on data from the Eurostat database

Between 2014 and 2023, general government expenditure on recreation, culture and religion in both the Czech Republic and Slovakia showed a steady upward trend. In the Czech Republic, this spending increased from EUR 2,141.9 million in 2014 to EUR 4,169.3 million in 2023, an increase of approximately 95%. A similar development can be observed in Slovakia, where spending increased from EUR 726.3 million in 2014 to EUR 1,408.3 million in 2023, an increase of 94%. However, in absolute terms, the Czech Republic's spending significantly exceeded Slovakia's throughout the period under review, with Slovakia's spending at approximately one third of Czech spending. This ratio has not changed significantly over the years, suggesting parallel development without any major convergence between the countries. The most significant increase in spending in the Czech Republic occurred between 2017 and 2018, while in Slovakia the largest jump was recorded between 2021 and 2022. The development in both countries can be related to the gradual strengthening of cultural policy, recovery from the economic crisis and the pandemic period, as well as investments in cultural and recreational infrastructure. In the long term, it can be stated that spending in this area has grown in parallel with the growth of public budgets, with culture, recreation and religion maintaining a stable position in the structure of public administration spending in both countries.

Employment in the cultural and creative industries sector is a significant indicator of its economic importance. At the global level, the sector offers approximately 30 million jobs, mainly in areas such as visual arts, the music industry and non-periodical press. However, in the context of the Slovak Republic, employment in this sector reaches significantly lower values. According to data from the Cultural and Creative Industries Satellite Account, 34,423 people were employed in these sectors in Slovakia in 2019, which represents only 1.4% of total employment in the national economy. For comparison, in the Czech Republic, employment in the cultural and creative industries sector was approximately 80,000 people in 2020, which corresponds to almost 2% of total employment. Both countries thus lag behind the average of European Union countries, where in 2015 approximately 2.9% of employees worked in the cultural sector. These differences point to the limited development of the sector in Slovakia and the potential for its further growth and strengthening of employment. In addition to employment, an important aspect of the economic assessment is also the level of international trade exchange – i.e. the import and export of cultural and creative goods. In this respect, the Slovak sector shows signs of significant economic closure towards foreign countries. Although the share of the sector in GDP is comparatively similar in the case of Slovakia and the Czech Republic, foreign trade data reveal significant differences. In 2019, the import of cultural and creative goods in Slovakia amounted to approximately 60 euros per capita, while in the Czech Republic it reached the level of 208 euros per person. In the area of exports, the differences are even more significant – while Slovak exports reached a value of only 40 euros per capita, in the Czech Republic it was 236 euros per person. These data point to the relatively low participation of Slovakia in the international market for cultural and creative products and the potential for strengthening the export performance of this sector. In summary, it can be stated that the cultural and creative industries in Slovakia are lagging behind not only in terms of employment, but also in their ability to engage in international trade. This knowledge should be taken into account when creating strategic documents and public policies to support a cultural and creative ecosystem that has the potential to contribute not only to economic growth, but also to strengthening identity, innovation and social cohesion. The COVID-19 pandemic has represented an unprecedented shock to the cultural and creative sector, which has been among the most affected sectors of the national economy. Although a comprehensive quantitative assessment of its consequences is not yet available, preliminary indicators indicate extensive economic and social impacts. One of the most striking indicators of the pandemic's impact is the dramatic decline in attendance at cultural events. While the number of visits steadily exceeded 21 million per year between 2017 and 2019, in 2020 it fell to 7.8 million, a drop of around 65%. This decline was a consequence of the widespread closure of cultural institutions and restrictions on mass events as part of anti-pandemic measures. The pandemic also highlighted the long-standing structural problems of the sector, especially in terms of unstable working conditions. Given that a significant proportion of workers in the sector are self-employed (SZČO) or employed in small and medium-sized enterprises, they are exposed to increased vulnerability to sudden drops in income. This uncertainty is also evidenced by the results of an international survey by the International Council of Museums (ICOM) from 2020, according to which up to 25% of freelance museology professionals considered a complete change of professional orientation during the pandemic. We drew on the data from the Cultural and Creative Industries Satellite Account, which provides a statistical assessment of the economic performance of this sector. Nevertheless, the already available indicators – such as the aforementioned drop in visitor numbers – point to the extent of the impacts and the urgency of the need for systemic measures to stabilize and revitalize the cultural and creative environment. The pandemic has not only caused a temporary interruption of the activities of many cultural institutions, but has also deepened existing inequalities and threatened the sustainability of the entire sector.

4. Conclusion

The aim of the presented analysis was to identify the relationships between the share of renewable energy sources, the amount of expenditure on culture and recreation, the share of people working in creative professions and the level of energy self-sufficiency of European countries. The results of the correlation matrix showed in particular a moderately strong positive correlation between the share of renewable energy sources and the level of energy self-sufficiency, which indicates that the development of renewable technologies significantly contributes to reducing dependence on external energy supplies. Regression analysis confirmed that the only statistically significant variable affecting energy self-sufficiency was the share of renewable energy sources. Expenditure on culture and recreation and the share of creative workers did not appear to be significant predictors in the model, which may be related to other intervening factors or the limited sample size. The findings point to the importance of investments in renewable energy sources as a tool for increasing the energy independence of countries. Future research would be useful to extend the model to include other relevant variables, such as technological level, energy policy or energy efficiency level. Cultural and creative industries are at the heart of many transformations shaping contemporary society – from digital innovation, climate challenges, a crisis of trust in democracy, to the redefinition of work and institutional credibility. Their ability to connect human imagination, values and technology predetermines them to play a fundamental role in the search for a sustainable and inclusive future. Creating appropriate political, economic and legal frameworks that support their potential should therefore be a priority in the strategic planning of every modern society.

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The Information System as an Assumption of Procurement Risk Management Effectiveness in Industrial Enterprise

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Abstract: The aim of this paper is to create an overview of the most relevant findings in the field of using information systems in purchasing management in industrial enterprises and to determine their impact on the effectiveness of purchasing risk management. In order to examine the relationship between Information system and effectiveness of Procurement risk management in detail we conducted qualitative research. The results of qualitative research lead to proving the need for an Information system as an assumption of Procurement risk management effectiveness. An information system can significantly improve procurement risk management by leveraging digital tools such as digital monitoring, risk identification and assessment classifiers, and integrating supplier relationship management with risk management.

Keywords: Information System; Procurement Risk Management; Effectiveness of PRM, Industrial Enterprise

Introduction

Many researchers are studying the impact of information systems on individual business functions and on the effective management of the business. Information systems increase the performance of an organization by providing high-quality information that supports effective analysis and strategic planning. By integrating robust IS, organizations can optimize their investments and achieve better operational results, which ultimately leads to improved decision-making skills and improved overall performance in a competitive business environment (Zohry, Al-Dhubaibi, 2024). Nowadays, it is impossible to manage businesses, organizations and make professional decisions without information and the use of information and communication technologies. Managers of various organizations need relevant information for effective management. Such information is essential for good decision-making (Bolek, Kokles, Romanová, Zelina, 2018).

High-quality information reduces uncertainty and helps in selecting optimal alternatives, leading to better decision-making (Nabot, 2023). In addition, information systems provide real-time monitoring and control capabilities through performance measurement tools, including key performance indicators, helping organizations track progress and identify inefficiencies, facilitating proactive problem-solving. They enhance the quality of decision-making at all levels of management by organizing accurate and relevant data that supports timely and effective judgments. Ultimately, information systems facilitate better administrative tasks and decision-making processes, leading to improved organizational performance (Sriramkumar et al. 2024). Management information systems should provide timely, relevant, and accurate information that is essential for achieving short-term, medium-term, and long-term goals. In a competitive environment, effective use of IS allows managers to use resources efficiently, increasing their ability to respond to changes and competitive challenges.

If we want to deal with the information system and its impact on purchasing risk management in industrial enterprises, we must first clarify the relationship between risk management and the purchasing or procurement process. As is generally known, risk management is not a separate function or organizational component of a company. Risk management should be an integral part of business processes. It follows that purchasing risk management should be part of the company's purchasing process. Since there is no clear definition of purchasing risk management, Hong, Lee and Zhang (2018) point out that procurement risk management should be implemented by reducing exposure (risk exposure) and at the same time reducing uncertainty in price, delivery time and demand so as to ensure a continuous flow of supplies (material, skills, capabilities, equipment) with minimal possible disruption.

The best way to demonstrate the impact of information systems on purchasing risk management is to determine the functions and tasks of IS in the individual phases of the procurement process. An important aspect is the links between all departments of the company and the need for information flows between them. At the same time, it should be considered that purchasing is an interface between the company's internal customers and suppliers. The company should have an information system that enables a smooth, trouble-free supply of material inputs for the company. Effective purchasing management will depend on timely, high-quality and relevant information coming from both the company's internal environment and its surroundings. This mainly concerns information regarding material needs, their availability on the market, the possibility of substitutions, supply conditions, payment options and other things. The summary of adequate information contributes to quality decisions in procurement and thus the efficiency and performance of the entire company.

1. Literature Review

In the following sections, we show the links between purchasing and other departments of the industrial enterprise, the information flows between them and the forms in which information is transmitted. The need for information in the relationship of the company with its suppliers is no less important. The combination of information needs from the internal and external environment gives us an overall view of the importance of the information system in the entire procurement process of an industrial company.

1.1. Purchasing department and information needs

The purchasing function in manufacturing companies is mainly provided by a department - the purchasing or supply department. In addition to the purchasing department, there is also an informal department of the purchasing center in the company. This may include, for example, project teams that meet regularly for business case meetings. Usually, these are users, approvers, decision-makers, advisors, buyers, influencers, filters and payers. One of the first tasks of the purchasing center is to decide how all the inputs necessary for the transformation process will be procured (by purchase, in-house production or cooperation). Each member of the purchasing center brings a lot of information based on which strategic decisions are made in purchasing and supply.

Sales provide accurate sales forecasts, historical sales data but also points to external factors affecting demand (Selvakumar et al., 2024). It is an important informant about changes required by the customer. This information is essential for effective planning of material requirements, ensuring the optimal level of production and minimizing potential losses due to demand mismatch (Tomar, Bharti, Sharma, 2024).

In some industrial sectors (mechanical engineering or electrical engineering), the existence of a design and production preparation department is typical. Its goal is to design a new product, develop documentation for products and production processes in the form of design drawings and projects. The design determines the product's shape, function, performance, dimensions, and other important parameters (Dupaľ et al., 2019). In addition to design drawings, bills of materials (lists of all components, materials used, and complete parts of a product) and material master records are important sources of information for purchasing.

The department of technological preparation of production has the task of determining the way in which individual production operations participate and in what sequence at individual workplaces and with what tools, until finally a finished part is created, a product for final assembly (Dupaľ et al., 2019). DTPP also partially ensures material preparation, when it determines the use of the material, its specific and total consumption. Information and consumption of individual materials in quantities and time throughout the entire production process are important for purchasing. This involves a precise specification of the material used and semi-finished products produced in previous production phases, marking the place of delivery - warehouse, workshop (Tomek and Vávrová, 2014). A precise specification means a clear determination in terms of type, size, quality standard or color. In industries such as the food and pharmaceutical industries, there are precise recipes that are used in the transformation process. Production planners play an important role within DTPP. From the point of view of supplying the company with material inputs, it is very important for purchasing to know the production plan, from which the purchasing plan is created.

1.2. Purchasing department and suppliers – information flow

We also understand purchasing as an interface between suppliers and internal customers of the company. This mainly concerns the design and technical preparation of production, production itself, research and development, human resources, warehouses, legal or financial departments. Information is sent and received by the purchasing department and suppliers throughout the entire procurement process, from inquiry to delivery of material inputs to the company.

After defining the need and precise specification of the purchased material, the phase of securing resources comes, which is referred to as sourcing. The company tries to find the most suitable suppliers. In the past, various yearbooks, catalogs obtained during fairs and exhibitions, telephone directories, etc. were used to find suppliers. The Internet has made it more efficient to find new suppliers not only in the domestic but also in the foreign environment. To address the supplier, to inquire, various forms of request are used according to the purpose of use. Foreign authors distinguish RFI (request for information), RFQ (request for quotation) and RFP (request for proposal).

RFI or Request for Information is used to gather information about potential suppliers and their ability to deliver. It helps businesses assess the potential of the supplier market without requesting a specific quote. According to Langer (2016), it usually leads to the creation of a shortlist of suitable suppliers. RFQ is aimed at obtaining quotes for simple purchases of products and services that are clear and well-defined. The goal is to easily compare the quotes received through simple comparison tables.

Request for Proposal – RFP is used for complex purchases - complex projects where the company is looking for innovative solutions. The buyer asks suppliers for detailed proposals to solve a given problem. RFP allows for a comprehensive evaluation based on multiple criteria, such as technical requirements but also costs (Al-Fedaghi & Al-Otaibi, 2018).

The purchasing department manages many documents that are useful in achieving purchasing objectives. Sangri Coral lists "purchasing documents". These are the twelve most used documents in printed or electronic form. They are the list of requirements, the quotation, the list of requests for quotations – the list of inquiries, the list of received quotations, the comparison table, the list of orders and concluded contracts, the list of pending deliveries, the list of payment orders, the list of payments, delivery notes, the report on the return of delivery and missing materials and the list of suppliers.

1.3. Information in procurement process

Purchasing is a process consisting of sub-processes and activities aimed at achieving the desired output. The basis of the corporate purchasing model according to Oreský (2011) is precisely the process approach. Other principles of the model include integration, relationships, economy and efficiency. The main processes and activities of this corporate purchasing model are followings.

Initial situation in the company, analysis of the current state. It is essential for the company to know what influence external and internal factors have on the purchasing process. At this stage, it is necessary to collect and process information from the external environment in the form of a PESTEL analysis. All subsequent steps in the purchasing process are also influenced by internal factors, which include company resources, company culture, characteristics of the value-creating process in the company, main tasks and priorities such as TQM or Just in time deliveries.

In the phase of identifying and determining the needs of the company, information is needed on what, when and how it will be produced. Based on information from members of the purchasing center, the exact need for input materials necessary for the production of the final product is determined. Depending on the industry and type of production, bills of materials, material master records or a production plan are used to identify needs.

ERP systems, usually tailor-made combinations of several modules such as accounting and reporting, finance, property, human resources and payroll, warehouse management, purchasing, sales, production, trade and marketing, production planning and management, etc., help identify and determine needs and plan resources, select suppliers, and assess suppliers. (Miklošík, 2014). Many authors agree on the benefits that ERP brings to companies. These include mainly reduced administrative costs, increased turnover, reduced inventories, increased productivity and flexibility, and improved decision-making (Staehr et al. 2012, Hart et al., 2014). Bustinza, Perez-Aroustegui, and Ruiz-Moreno demonstrate the influence of corporate culture and customer orientation on the creation of an effective ERP system that brings valuable outputs to the company for making important purchasing decisions (Bustinza et al. 2013).

2. Methodology

In order to write this article, it was necessary to study monographs and scientific articles published in domestic and foreign scientific journals found in the Ebsco and Google Scholar databases from 2014 to 2024. We divided the topic Impact of information systems on effectiveness of procurement risk management into several logical areas, which were our keywords: performance of procurement, effectiveness of procurement risk management, impact of information systems on procurement performance, impact of information systems on procurement risk management, procurement process and information need, factors of information system adoption. From the articles, which were sorted by relevance and date of publication, we had to select those that dealt with public procurement. Thus, we obtained 31 literary sources, which we processed in individual chapters. The Industrial market is characterized by high heterogeneity therefore we conducted qualitative research. In order to examine the relationship between information system and effectiveness of Procurement risk management in detail, we carried out semi-structured interviews. Among five respondents were purchasers and managing directors of engineering enterprises. Our interviews focused on identifying all types of information needed in the procurement process on industrial enterprises.

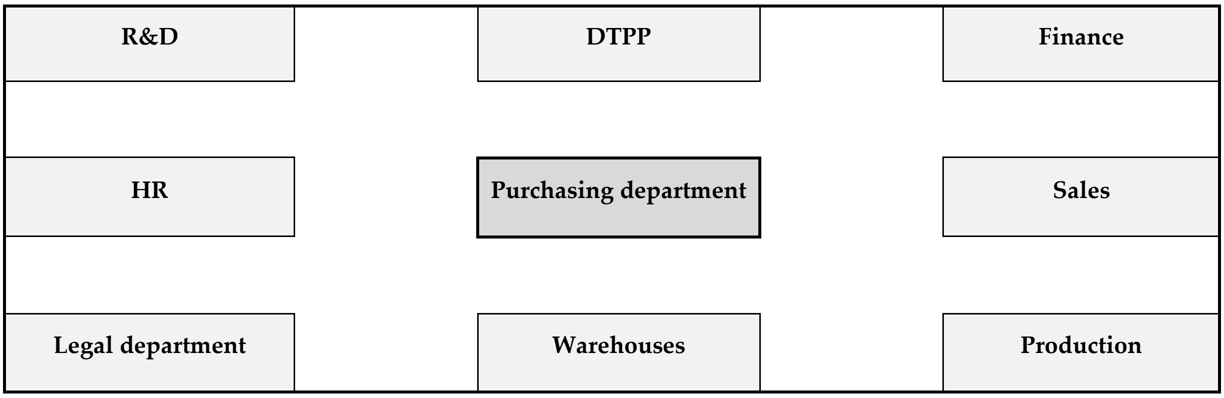
3. Results

In different phases of the procurement process, the need for information, its search, sorting, processing and storage is different. The requirements of information system users for timeliness, form, content and amount of information are also different.

3.1. Purchasing department and information needs

The purchasing function in manufacturing companies is mainly provided by a department - the purchasing or supply department. In addition to the purchasing department, there is also an informal department of the purchasing center in the company. As we can see in Figure 1, this brings together various participants in purchasing decisions, whose reasons for making decisions are determined by their role and function in the company (purchasing, sales, production, planning, finance, human resources, etc.).

Figure 1. Informal center of procurement



Source: Own processing

Sales, or rather the department responsible for the sale of finished products of a company, is the bearer of a lot of important information about customer demand. It is also a kind of interface between the internal and external (customer) environment of the company. Purchasing requires sales to have an overview of the expected demand for the product, purchasing intentions and customer preferences.

The purchasing department must exchange very important information with the legal department. This is usually responsible for preparing business contracts with customers and suppliers of the company. Purchasing provides basic information about the selected supplier. The legal department creates business contracts for purchasing in accordance with legal regulations and the goals of the company. The result is purchase and sale contracts, work contracts, framework agreements, general purchase agreements, etc. During negotiations with suppliers, many unexpected situations may arise that need to be responded to and the agreement between partners consulted with the legal department.

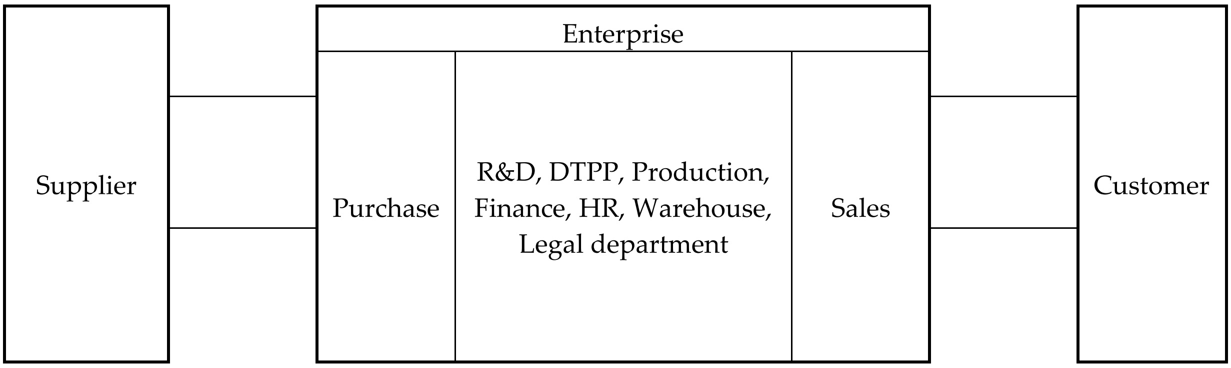
One of the members of the purchasing center, which plays the role of approver and payer, is the financial department. Purchasing provides the financial department with preliminary information on the prices of purchased materials, forwards invoices from suppliers. The financial department is responsible for making payments to suppliers for the delivered materials. It also monitors the financial indicators of purchases, approves the payment terms of purchases.

Depending on the industry and size of the company or the type of production, there may be other departments (departments, sections) in the company that are part of the above-mentioned departments or are separate organizational units that perform professional activities that assist the entire production process. These may include functions such as research and development, warehouse management, transport, logistics, human resource management, marketing or quality. Each of these departments provides purchasing with important information necessary to make the right decisions. The information must be accurate, relevant and delivered on time to contribute to the effective operation of purchasing and thus increase the performance and competitiveness of the company.

3.2. Purchasing department and suppliers – information flow

We consider purchasing as an interface between suppliers and internal customers of the enterprise, as shown in Figure 2. This mainly concerns the design and technical preparation of production, production itself, research and development, human resources, warehouses, legal or financial departments. Information is sent and received by the purchasing department and suppliers throughout the entire procurement process, from inquiry to delivery of material inputs to the company.

Figure 2. Purchasing department and sales like enterprise interface



Source: Own processing

After defining the need and precise specification of the purchased material, the phase of securing resources comes, which is referred to as sourcing. The company tries to find the most suitable suppliers. In the past, various yearbooks, catalogs obtained during fairs and exhibitions, telephone directories, etc. were used to find suppliers. The Internet has made it more efficient to find new suppliers not only in the domestic but also in the foreign environment. To address the supplier, to inquire, various forms of request are used according to the purpose of use. Foreign authors distinguish RFI (request for information), RFQ (request for quotation) and RFP (request for proposal).

After evaluating the price offers, whether for simple or complex purchases, the phase of securing resources may occur. The conclusion of business contracts or the sending of the order is preceded by negotiations on prices, quantities, business and payment terms. In the event of an agreement, it is necessary to carry out administrative actions related to the creation and signing of contracts. The legal departments of both the supplier and the customer are responsible for these acts. Information systems are very useful at this point and streamline the entire procurement process. Depending on the significance of the business transaction, a person from the legal department may also be part of the negotiation team. In the event of their absence, the legal department must be informed immediately about all agreed conditions so that contracts can be drawn up and subsequently signed.

In the case of simple purchases, it is sufficient to create a binding order in the corporate information system based on the need and send it to the supplier for confirmation. Subsequently, deliveries are made, and further information is exchanged through delivery notes, various certificates, customs declarations and invoices from the supplier. The information system should be helpful in creating, sending or storing these documents for further processing.

3.3. Information in procurement process

It should be noted that these three previous phases of the purchasing process require the implementation of risk management. The ISO 31000 Risk Management standard also divides the risk management process into several phases that we can align with the purchasing process. These are creating context, risk identification, risk analysis, risk assessment, risk treatment, communication and monitoring. Since risk management should be part of the purchasing process, activities related to risk assessment are also purchasing activities. The information needed to assess risk comes from both the internal (material master records, supplier cards, business case evaluations, etc.) and external (suppliers, competitors, the public, etc.) environment.

After the purchasing center has decided what, when and how to procure, the sourcing phase comes next. In this phase, the company communicates with suppliers. The company requests offers from suppliers. These requests can be in the form of RFP (request for proposal) or RFQ (request for quotation). RFI (request for information) requests are required in the previous phases of the purchasing process.

In the next phase, the actual implementation of business relationships occurs. Purchase contracts and orders are concluded. The company's information system facilitates the administration and management of purchase contracts. They must be available at any time. Part of the implementation of business relationships is also monitoring the performance of suppliers and ensuring intra-company distribution. The information system creates conditions for evaluating the performance of suppliers.

From the point of view of the information system, the last phases of the procurement process are also interesting, namely monitoring and managing the economic aspects of purchasing and measuring and evaluating purchasing performance. Data collected throughout the procurement process is analyzed, evaluated and stored in order to provide accurate, relevant information in the future for decision-making at the strategic, tactical and operational levels in the area of procurement management, as well as procurement risk management. These include various indicators of performance, efficiency, profitability, risk, etc.

4. Discussion

The impact of the information system on the effectiveness of purchasing management.

The information system improves procurement management by facilitating coordination between procuring units and suppliers, reducing bid processing time, minimizing data processing errors, and enabling real-time monitoring, ultimately leading to increased efficiency, transparency, and accountability in the procurement process (Bakhar, Evantina, Albab, 2024).

According to Zhang and Ma (2024), a business uses a wealth of data, artificial intelligence, and automation to accurately forecast demand, optimize supplier selection, ensure contract compliance, and improve inventory management, thereby reducing costs and increasing transparency, making the procurement process traceable and improving overall supply chain efficiency (Zhang, Ma, 2024).

Kodaneva and Kovrizhnykh (2024) state that an information system increases the efficiency of procurement management by optimizing processes, improving control and transparency, reducing costs, increasing procurement quality, supporting better supplier cooperation, enhancing the company's reputation, and increasing competitiveness, provided that it is well developed and constantly adapted to organizational needs.

The information system integrates technologies throughout the supply chain, improves visibility, streamline processes, and enables faster responses to market changes, ultimately leading to better decision-making and business performance (Amira, 2024). It facilitates better collaboration with suppliers, leading to higher procurement quality, improved company reputation, and increased competitiveness, ultimately leading to overall procurement management effectiveness (Varfolomeeva, Ivanova, 2023).

Digitalization increases the efficiency of procurement by minimizing risks, increasing speed, and improving quality, leading to cost savings. In addition, it enables the identification and elimination of supply chain failures, promotes greater transparency, and facilitates the development of new key performance indicators (Bakulina, Kaprova, Gusev, 2019). Centralization and categorization of procurement increase efficiency by achieving economies of scale, strengthening bargaining positions, and increasing transparency, which together reduce costs and reduce the likelihood of corruption and fraud in procurement processes (Anikevich, Prodanova, 2022).

An information system can significantly increase the efficiency of procurement management by optimizing processes, automating them, thus reducing the administrative burden, better coordination between the company and the supplier, improving transparency, improving control, minimizing risks and using advanced technologies, artificial intelligence. Although the benefits of information systems for procurement management are significant, the need for continuous improvement of systems, data security and technological obsolescence must be considered.

The impact of the information system on the effectiveness of purchasing risk management.

Information systems can significantly improve procurement risk management by leveraging digital tools, using data analytics to streamline processes and improve decision-making. By integrating various technology solutions, businesses can proactively identify and mitigate risks associated with procurement activities. IS can help by providing continuous digital monitoring, identifying and assessing risk through machine learning applications, and integrating supplier relationship management with risk management.

Digital monitoring

By digitizing monitoring, the information system improves procurement risk management, enables continuous oversight of transactions, correlates internal and external data, and provides recommendations regarding anomalies (Banerjee, 2022). Businesses can analyze historical data to identify abnormal delivery, material consumption, price, or various expenses, allowing for timely intervention and thus reducing the likelihood of fraud and non-compliance with agreed terms.

Using classifiers

According to Hoover et al. (2017), the use of machine learning classifiers to evaluate bids also makes procurement risk management more efficient. The application is able to create price scores, supplier scores, and supply risk scores. In this way, IS can identify high-risk purchases and thus improve overall procurement efficiency.

Integrating SRM with Risk Management

The information system improves procurement risk management by integrating supplier relationship management (SRM) with risk management capabilities, improving supplier visibility (Mizgier, 2024). It uses supplier relationship analytics, transforms raw data into actionable insights, effectively assesses risks in line with various regulatory changes, and thus enables the creation of targeted strategies.

The information system allows for flexible adaptation of risk assessment standards, facilitates proactive risk identification and improves communication with stakeholders, ultimately leading to better decision-making (Sassaoui, El Alami, Hlyal, 2023). According to Ikram, Afaf and Latifa, (2023), it enables real-time data analysis, improves supplier relationship management and process automation. This digitalization supports greater flexibility and control, allowing companies to proactively identify and mitigate potential risks in purchasing activities. Makarenko (2023) states that IS enables the implementation of a hybrid risk management model, further enables real-time adjustments to supplier assessment criteria and facilitates the creation of detailed risk profiles. Despite the significant benefits, businesses must be careful not to over-rely on technology, as this can lead to neglecting the human factor in risk management.

Factors influencing the adoption of IS in procurement

Key factors influencing the adoption of information systems in procurement processes include technological factors such as perceived efficiency benefits and perceived ease of use, organizational factors such as business-to-business expertise, information sharing culture and top management support, and environmental factors, particularly pressure from trading partners. Zulkarnain, Muda, Kesuma, (2023) include political, socio-economic and demographic aspects, along with government regulations and supplier participation. Internal organizational support, network connectivity, organizational culture and perceived resource availability also play a significant role.

5. Conclusion

The need for a high-quality and efficient information system in purchasing management increases with the number of transactions or purchased items, the number of suppliers and the requirement of sustainability and competitiveness. Understanding purchasing as an interface between the supplier and internal customers implies the need to build an information system capable of connecting the internal and external environment of the company, bringing timely and accurate information that helps in making the right decisions throughout the procurement process. The integration of digital tools facilitates better coordination between stakeholders, shortens processing time and minimizes errors, which ultimately leads to a more efficient procurement cycle.

An information system can significantly improve procurement risk management by leveraging digital tools such as digital monitoring, risk identification and assessment classifiers, and integrating supplier relationship management with risk management. Despite the significant benefits, businesses must be cautious about over-reliance on technology, as this can lead to neglect of the human factor in risk management.

Building information systems for procurement and risk management processes is influenced by various factors that cover technological, organizational and environmental areas. These factors are opposed by inhibitors such as uncertainty, resource constraints and resistance to change. Companies must deal with these challenges to successfully implement and benefit from advanced information systems.

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New trends in the use of AI in business diagnostics and their application in business practice

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Abstract: The growing importance of artificial intelligence (AI) in the field of business diagnostics brings new possibilities for identifying problems and optimizing processes. This article examines current trends, practical applications and the potential of artificial intelligence in improving business performance. Based on an analysis of the literature and case studies, the main advantages, challenges and recommendations for implementing AI in diagnostic processes are presented.

Keywords: artificial intelligence (AI), business diagnostics, optimizing processes, internal and external environment, machine learning, natural language processing

Introduction

Artificial intelligence (AI) stands out as a transformative technology of our digital age – and its practical uses across the economy are growing rapidly.

Business diagnostics is the process of evaluating the internal and external environment of a company in order to identify weaknesses and look for opportunities for improvement. In the last decade, artificial intelligence has been increasingly used to streamline these processes thanks to its ability to process large volumes of data and find hidden patterns.

1. Literature Review

In the first part of the scientific paper, we define artificial intelligence (AI) and its partial systems from a global perspective.

Through the perspectives of various authors, we will present the current state of the issue. Based on schematic and tabular processing, we will provide information in a structured and clear form.

Artificial intelligence processes data to make decisions and predictions. Machine learning algorithms allow artificial intelligence to not only process that data, but to use it to learn and become smarter, without the need for any additional programming. Artificial intelligence is the parent of all the subsets of machine learning below it. Within the first subset is machine learning; within that is deep learning, and then within that is neural networks. (SAP, 2025)

Machine learning is a subset of artificial intelligence (AI). It focuses on making computers learn from data and improve with experience—rather than being explicitly programmed to do so. In machine learning, algorithms are trained to look for patterns and correlations in large data sets and make the best decisions and predictions based on that analysis. Machine learning applications improve with use and become more accurate the more data they have access to. (SAP, 2025)

Machine learning allows experts to "train" a machine by making it analyze massive datasets. The more data the machine analyzes, the more accurate results it can produce by making decisions and predictions for unseen events or scenarios. Machine learning models need structured data to make accurate predictions and decisions. If the data is not labeled and organized, machine learning models fail to comprehend it accurately, and it becomes a domain of deep learning. The availability of gigantic data volumes in organizations has made machine learning an integral component of decision-making. Recommendation engines are the perfect example of machine learning models. (Sajid, H., 2023)

There are four types of methodologies in machine learning:

- Supervised learning – It needs labeled data to give accurate results. It often requires learning more data and periodic adjustments to improve outcomes.
- Semi-supervised – It's a middle tier between supervised & unsupervised learning that exhibits the functionality of both domains. It can give results on partially labeled data and doesn't require ongoing adjustments to give accurate results.
- Unsupervised learning – It discovers patterns and insights in datasets without human intervention and gives accurate results. Clustering is the most common application of unsupervised learning.
- Reinforcement learning – The reinforcement learning model requires constant feedback or reinforcement as new information comes to give accurate results. It also uses a "Reward Function" that enables self-learning by rewarding desired outcomes and penalizing wrong ones.

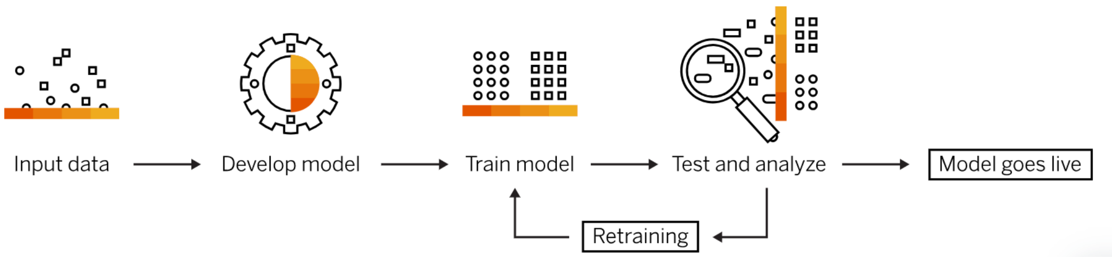

Figure 1. Machine learning process

Source: SAP (2025).

Deep learning is the type of machine learning. It is called "deep" because it involves many layers of neural networks and vast amounts of complex and disparate data. To achieve deep learning, the system interacts with multiple layers in the network, extracting increasingly higher-level outputs. Examples of deep learning applications include speech recognition, image classification, and pharmaceutical analysis. (SAP, 2025)

Machine learning models need human intervention to improve accuracy. On the contrary, deep learning models improve themselves after each result without human supervision. But it often requires more detailed and lengthy volumes of data.

The deep learning methodology designs a sophisticated learning model based on neural networks inspired by the human mind. These models have multiple layers of algorithms called neurons. They continue to improve without human intervention, like the cognitive mind that keeps improving and evolving with practice, revisits, and time. (Sajid, H., 2023)

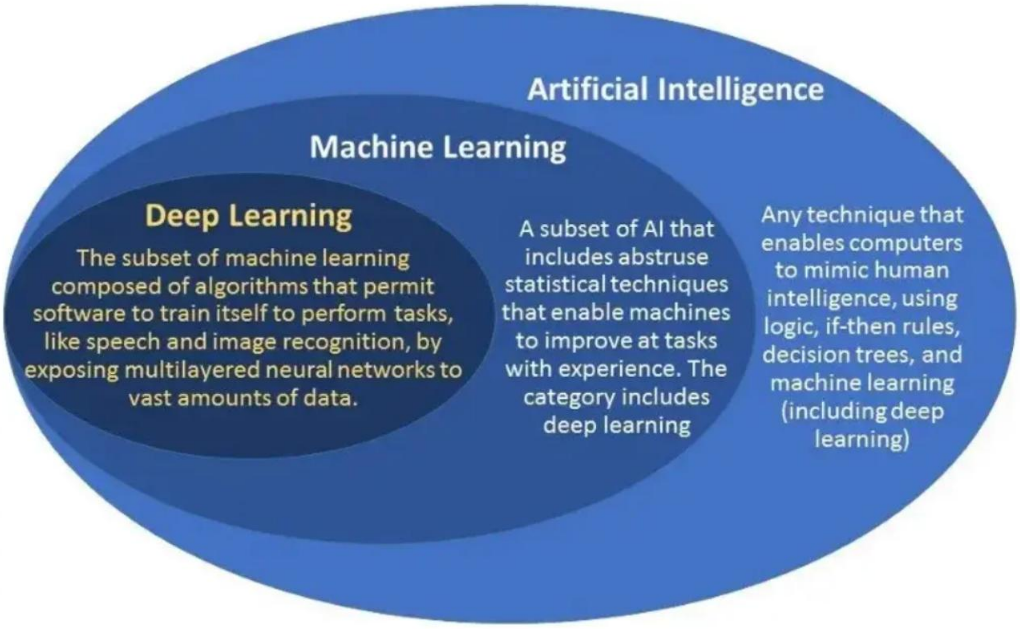

Figure 2. Machine learning vs. deep learning

Source: Sajid, H. (2023).

Terminologies like Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning are hype these days. People, however, often use these terms interchangeably. Although these terms highly co-relate with each other, they also have distinctive features and specific use cases.

AI deals with automated machines that solve problems and make decisions imitating human cognitive capabilities. Machine learning and deep learning are the subdomains of AI. Machine Learning is an AI that can make predictions with minimal human intervention. Whereas deep learning is the subset of machine learning that uses neural networks to make decisions by mimicking the neural and cognitive processes of the human mind. (Sajid, H., 2023)

The above image illustrates the hierarchy.

2. Methodology

From a methodological point of view, we approached the processing of the issue of AI implementation in the field of business diagnostics by systematically analyzing the collected theoretical foundations for the research issue. Using synthesis, induction and deduction, we came to the formulation of theoretical foundations for processing the research part of the paper. In the research part, we used statistical surveys, observations and questionnaires as the primary source of data. The target group were companies that use AI in business diagnostics and have AI systems implemented at multiple levels of corporate structures and processes. We analyzed the obtained data and, through their comparison, we provoked a discussion, on the basis of which recommendations and conclusions were drawn. We used diagrams and table processing to clearly systematize the data.

3. Results

In the results section of the scientific paper, we will focus on the potential uses and benefits of AI in business practice, especially in the area of business diagnostics. We will also point out the limitations, risks, and challenges associated with the implementation of AI systems.

3.1. Applied experience with AI

Drawing on McKinsey Global Institute research and the applied experience with AI of McKinsey Analytics, we assess both the practical applications and the economic potential of advanced AI techniques across industries and business functions. Our findings highlight the substantial potential of applying deep learning techniques to use cases across the economy, but we also see some continuing limitations and obstacles—along with future opportunities as the technologies continue their advance.

Ultimately, the value of AI is not to be found in the models themselves, but in companies' abilities to harness them. Institute mapped both traditional analytics and newer "deep learning" techniques and the problems they can solve to more than 400 specific use cases in companies and organizations. (Chui, M., Manyika, J., & Miremadi, M., 2018)

The research provides an overview of the areas within specific sectors where deep neural networks have the potential to create the most value. The study reports on the incremental gains that these neural networks can generate compared to traditional analytics, and the demanding data requirements – in terms of volume, variety and velocity – that must be met to realize this potential.

Examples of where AI can be used to improve the performance of existing use cases include: (Chui, M., Manyika, J., & Miremadi, M., 2018)

- **Predictive maintenance**: the power of machine learning to detect anomalies. Deep learning's capacity to analyze very large amounts of high dimensional data can take existing preventive maintenance systems to a new level. Layering in additional data, such as audio and image data, from other sensors—including relatively cheap ones such as microphones and cameras—neural networks can enhance and possibly replace more traditional methods. AI's ability to predict failures and allow planned interventions can be used to reduce downtime and operating costs while improving production yield. For example, AI can extend the life of a cargo plane beyond what is possible using traditional analytic techniques by combining plane model data, maintenance history, IoT sensor data such as anomaly detection on engine vibration data, and images and video of engine condition.
- **AI-driven logistics optimization** can reduce costs through real-time forecasts and behavioral coaching. Application of AI techniques such as continuous estimation to logistics can add substantial value across sectors. AI can optimize routing of delivery traffic, thereby improving fuel efficiency and reducing delivery times. One European trucking company has reduced fuel costs by 15 percent, for example, by using sensors that monitor both vehicle performance and driver behavior; drivers receive real-time coaching, including when to speed up or slow down, optimizing fuel consumption and reducing maintenance costs.
- AI can be a valuable tool for **customer service management and personalization challenges**. Improved speech recognition in call center management and call routing as a result of the application of AI techniques allow a more seamless experience for customers—and more efficient processing. The capabilities go beyond words alone. For example, deep learning analysis of audio allows systems to assess a customers' emotional tone; in the event a customer is responding badly to the system, the call can be rerouted automatically to human operators and managers. In other areas of marketing and sales, AI techniques can also have a significant impact. Combining customer demographic and past transaction data with social media monitoring can help generate individualized product recommendations. "Next product to buy" recommendations that target individual customers—as companies such as Amazon and Netflix have successfully been doing--can lead to a twofold increase in the rate of sales conversions.

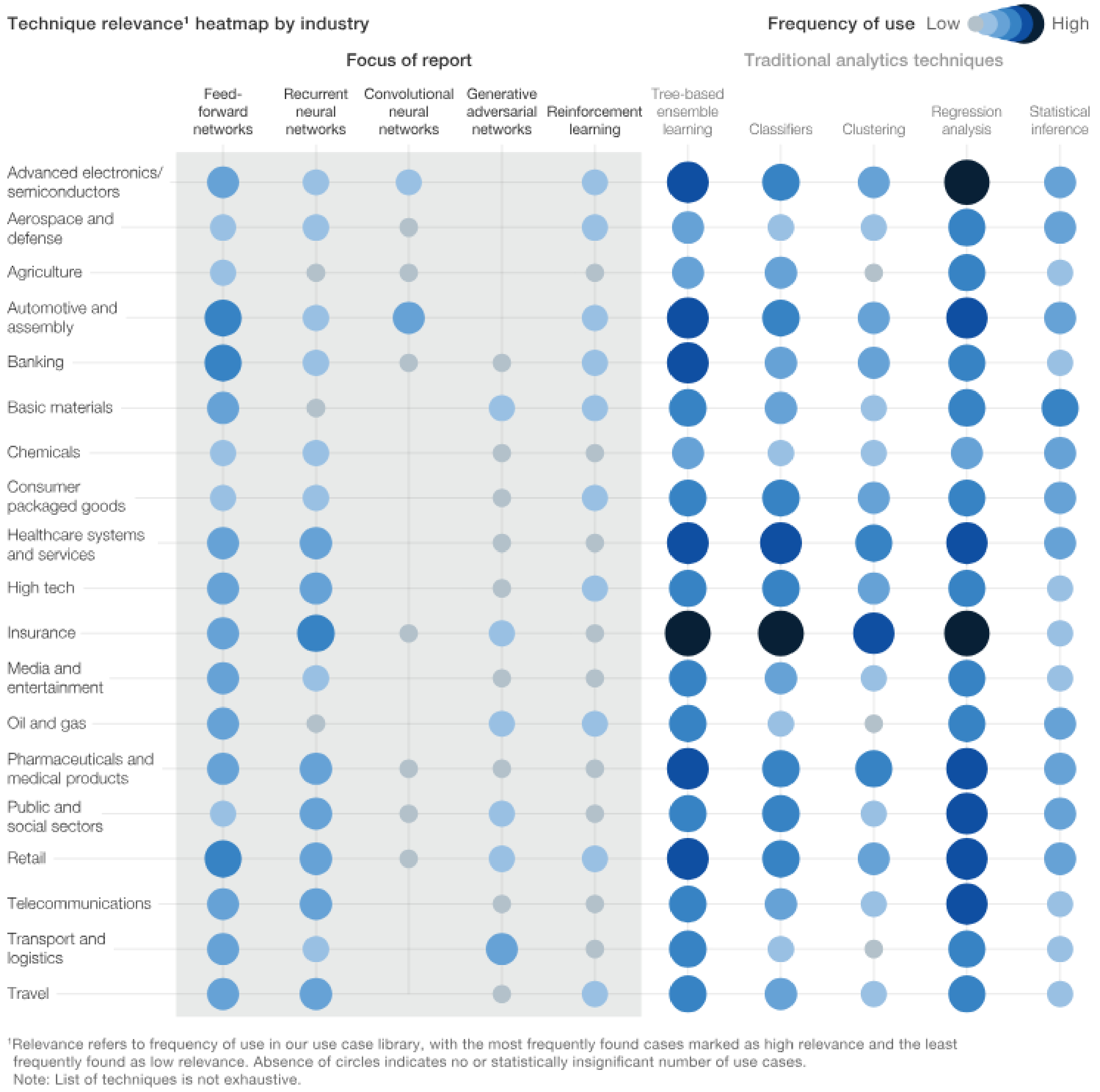

Figure 3. Advanced deep learning AI techniques applied across industries, alongside more traditional analytics

Source: Chui, M., Manyika, J., & Miremadi, M., (2018)

Sajid, H. (2023) points out in his research the differences between machine learning and deep learning

Table 1. Comparison of the differences between machine learning and deep learning

Differences	**Machine Learning**	**Deep Learning**
Human Supervision	Machine learning requires more supervision.	Deep learning models require almost no human supervision after development.
Hardware Resources	You build and run Machine learning programs on a powerful CPU.	Deep learning models require more powerful hardware, like dedicated GPUs.

Time & Effort	The time required to set up a Machine learning model is less than deep learning, but its functionality is limited.	It requires more time to develop and train data with deep learning. Once created, it continues to improve its accuracy with time.
Data (structured/unstructured)	Machine learning models need structured data to give results (except unsupervised learning) and require continuous human intervention for improvement.	Deep learning models can process unstructured and complex datasets without compromising accuracy.
Use-cases	eCommerce websites and streaming services that use recommendation engines.	High-end applications like Autopilot in planes, self-driving vehicles, Rovers on the Martian surface, face recognition, etc.

Source: own proceeding by: Sajid, H. (2023)

3.2. Using artificial intelligence in business diagnostics

Data intelligence and AI enable organizations to make data-driven decisions quickly and accurately. AI systems can find patterns, trends, and correlations in vast amounts of structured and unstructured data that humans can barely notice. Providing executives and employees with accurate and timely information empowers them to make the right decisions that drive the growth and success of their companies. Artificial intelligence tools such as machine learning and low-code/no-code platforms can automate time-consuming and repetitive operations. By leveraging AI-based automation, employers can free up critical human resources and allow employees to focus on strategic projects and value-creating activities. Automation increases operational efficiency while reducing the risk of errors, creating a more efficient and effective work environment. (Ralph, J. 2024)

By integrating data intelligence and AI, organizations can use predictive analytics to predict future trends and outcomes. Artificial intelligence (AI) systems can predict customer behavior, market trends, and operational pain points by examining historical data and using sophisticated algorithms. With this foresight, organizations can proactively change tactics, streamline processes, and stay ahead of the competition. Predictive analytics enables agile decision-making, as well as reducing risk and fostering a culture of continuous improvement.

Artificial intelligence is receiving attention in the field of business diagnostics, especially in the following areas (Davenport, T. H. & Ronanki, R., 2018):

- Predictive analytics: AI allows to predict future trends and problems based on historical data. (Chui, M., Manyika, J., & Miremadi, M., 2018)

- Pattern recognition: Machine learning algorithms can identify unusual behavior and potential errors in business processes.

- Automated reporting and recommendations: Generative AI models create diagnostic reports with recommendations for management.

- Increasing the effectiveness of decision-making: AI supports managers by providing fast and accurate analyses of complex data sets.

3.3. Implementation Challenges

While AI offers many benefits, there are also significant challenges (Goodfellow, I., Bengio, Y. & Courville, A., 2016):

- Data Quality: The success of AI depends on the availability of high-quality and properly structured data. Problem areas can include labeling training data, which often has to be done manually and is essential for supervised learning. The second is the difficulty of obtaining datasets that are large and complex enough to be used for training; for many business use cases, creating or obtaining such large datasets can be challenging.

- Ethical Issues: AI deployment must comply with legislative and ethical standards. The introduction of artificial intelligence (AI) into the corporate environment brings not only technological and economic benefits, but also a number of ethical dilemmas that cannot be overlooked. In the field of business diagnostics, these issues are mainly related to data protection, algorithm transparency, data bias and responsibility for decisions.

Figure 4. Ethics in AI
Source: Bharadiya, J. (2023)

- Costs and ROI: Implementing AI solutions can be financially demanding and does not always bring immediate returns. AI creates added value in every area of a company's operations, from the supply chain to finance, procurement, HR, sales and other areas. Finance teams can make a real impact on a company's bottom line with artificial intelligence that improves operating cash flow, increases revenue growth, and optimizes bottom line margin.

4. Discussion

We can conclude that data intelligence and artificial intelligence are key components of a high-performance workplace. Organizations can use data and AI algorithms to improve decision-making processes, automate operations, customize the environment for employees, use predictive analytics, and develop collaboration. Organizations can use these technologies to maintain agility, adapt to changing market conditions, and support sustainable growth. Organizations that prioritize the implementation of data intelligence and AI will gain a competitive advantage and will thrive in a dynamic business environment in the future.

Where AI techniques and data are available and the value is clearly proven, organizations can already pursue the opportunity. In some areas, the techniques today may be mature and the data available, but the cost and complexity of deploying AI may simply not be worthwhile, given the value that could be generated.

Similarly, we can see potential cases where the data and the techniques are maturing, but the value is not yet clear. The most unpredictable scenario is where either the data (both the types and volume) or the techniques are simply too new and untested to know how much value they could unlock.

Societal concerns and regulations can also constrain AI use. Regulatory constraints are especially prevalent in use cases related to personally identifiable information. This is particularly relevant at a time of growing public debate about the use and commercialization of individual data on some online platforms. Use and storage of personal information is especially sensitive in sectors such as banking, health care, and pharmaceutical and medical products, as well as in the public and social sector.

5. Conclusion

Artificial intelligence holds a significant place in the future of enterprise diagnostics. Organizations that can effectively implement AI into their diagnostic processes will gain a competitive advantage. Future research should focus on improving the interpretability of AI systems and minimizing ethical risks.

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Perspectives of renewable energy sectors development and creation of clusters within the EU countries

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Abstract: Energy is at the heart of the climate change problem and fundamental to its solution. A large amount of the greenhouse gases that blanket the Earth and trap the sun's heat are generated by energy production, through the burning of fossil fuels to generate electricity and heat. Fossil fuels, such as coal, oil, and gas, are by far the largest drivers of global climate change, responsible for more than 75% of total global greenhouse gas emissions and nearly 90% of all carbon dioxide emissions. The science is clear: to avoid the most negative impacts of climate change, we must reduce emissions by almost half by 2030 and reach net zero by 2050. To achieve this, we need to stop relying on fossil fuels and invest in alternative energy sources that are clean, accessible, affordable, sustainable, and reliable. Renewable energy sources, which are abundant in our environment, whether provided by the sun, wind, water, waste, or the Earth's own heat, are renewed by nature itself and emit few (if any) pollutants or greenhouse gases into the air.

Keywords: renewable energy, fossil fuels, sustainability

Introduction

Scientific and technological progress in society gives humans the ability to exercise great power over their environment. This leads to a variety of environmental problems that endanger the biosphere, the part of the planet where life develops and which integrates all ecosystems1, whether terrestrial, aquatic, aerial, or transitional. Humans act uncontrollably (e.g., burning fossil fuels, deforestation, etc.), leading to environmental collapse. This is a source of great concern for environmental ethics, as this field of knowledge emerges as a bastion to show humanity that it must regain awareness that it lives on a sacred planet of which it is a part. In contrast to the above approaches, this work aims to raise awareness about the need for balanced management of natural resources and encourages a commitment to the transition toward energy systems that have a broad participation of renewable energies and that generate a neutral carbon footprint2 based on the implementation of the concept of the four Rs of sustainable development: Reduce, Reuse, Recycle and Re-educate. These behavioral changes require prioritizing environmentalist perspectives and highlight the need to place educational institutions within an environmental framework, as they are vital for promoting sustainability. The sustainability paradigm is also found in university practice in an educational, research, and social transfer dimension. In 2023, the share of renewable generation was 68%. However, in the first six months of 2024, renewables generated 74% of the electricity generation across Europe. "The pace of change is impressive. These figures demonstrate that electricity companies' decarbonization efforts are years ahead of any other sector," said Kristian Ruby, Secretary General of Eurelectric. While the supply figures are promising, the same cannot be said for electricity demand.

1. Literature Review

Renewable energy generation in Europe is breaking records, reaching 74% of its production in the first months of 2024, according to data published by the Electricity Data Platform (ELDA), powered by Eurelectric. This is a significant increase compared to the 68% share in 2023. "The main reasons for this remarkable result were an unprecedented influx of renewables into the grid combined with the stabilization of the nuclear fleet," they explain. In the first half of 2023, EU electricity demand decreased by 3.4% compared to the same period in 2022 and has remained low in 2024: 2.6% lower than in the first half of 2022. This trend is mainly due to the relocation of industry abroad, warmer temperatures, energy savings, and slow economic growth. "Years of stagnation in electricity demand have now turned into a regular decline. Policymakers urgently need to support electricity consumption to provide the necessary investment signals for clean generation," In the released statement, Eurelectric (Federation of European electric energy) calls on the new Commission to propose an Electrification Action Plan within the first 100 days of its mandate, with an indicative target of 35% by 2030 and a clear electrification indicator to be incorporated into EU countries' National Energy and Climate Plans (NECPs) to monitor and achieve progress on the ground. Failure to act could result in the EU failing to meet its climate targets, reducing renewable energy production, and slowing down investment in the leading sector of the energy transition.

Non-conventional renewable energy sources (NCRES) such as: wind, solar photovoltaic, biomass, small hydroelectric plants, tidal, geothermal, among others, are sources of electricity generation considered clean because their level of greenhouse gas emissions is so insignificant that it can be negligible [1–5]. NCRES are renewable because their primary source of energy is renewable, cyclical, conserved, and for human life expectancy, the primary sources of NCRES are inexhaustible. For example, wind is the primary source of wind energy, the sun is the primary source of photovoltaic energy, water is the primary source of hydroelectric and tidal energy, as well as the high temperature of the earth inside in the vicinity of volcanoes, is the primary source of geothermal energy [1–5]. Thermal power plants are considered polluting because they use fossil fuels and emit greenhouse gases that increase global warming. They are considered non-renewable because their primary source is consumed and is therefore exhaustible, both physically and economically [1–5]. Electricity markets are based on an energy supply composed of different types of resources, mainly hydraulic and thermal, gas, coal and liquid fuels [3–5]. Recently, in Latin America, the use of FNCER has managed to enter the electricity market supply as a result of an energy policy of integration of clean and low-carbon energies to reduce CO2 emissions [6–8].

2. Methodology

The most commonly used processes to identify situation with electric industry is general evaluation and method which were used are generally used methods. The same is within industrial clusters determination, where we used generally accessible information and expert opinions, critical mass of enterprises in the region or complementary industries, concentration indices (location quotient, Gini indices, Ellison-Glaeser measures), input-output (factors and basic elements of analyses) and network analyses. The combination of several processes is possible from a multidimensional perspective. Feser and Sweeney (2002) complement these methodological approaches with spatial analyses, in which we can distinguish between separated and connected space and global versus local space. Separate space requires the use of previously unbounded spatial units (structures), usually administrative units, while connected spaces do not. Global indicators give information about general clustering trends, although they do not provide information about where the clusters are located.

3. Results

The European Leaders of Blue Energy (EUROCLUSTER ELBE) alliance of European clusters, led by the Energy Cluster Association, has been selected by the European Commission as a "Eurocluster" initiative in the renewable energy ecosystem. This Eurocluster is part of the European Commission's Industrial Strategy, structured around 16 priority industrial ecosystems, one of which is the "Renewable Energy Industrial Ecosystem." On September 13, the European Commission organized a virtual kickoff meeting with all the leading clusters of the 16 Euroclusters approved and funded by the EC under the "Joint Cluster Initiatives (EUROCLUSTERS) for Europe's Recovery" call. At this meeting, the Euroclusters' objectives, partners, and planned activities were presented. On September 2022, the ELBE EUROCLUSTER consortium held its internal kickoff meeting in Norway, hosted by partner GCE Node. The meeting served to establish the first steps to be taken in launching the project and review the various activities included in the work packages. The EUROCLUSTER ELBE alliance is comprised of seven European clusters: Pole Mer Meditarrenee (France), Offshore Vast (Sweden), Energy Cluster Denmark (Denmark), GCE Node (Norway), Blue Cluster (Belgium), Pomeranian Offshore Platform (Poland), and the alliance coordinator, ACE.

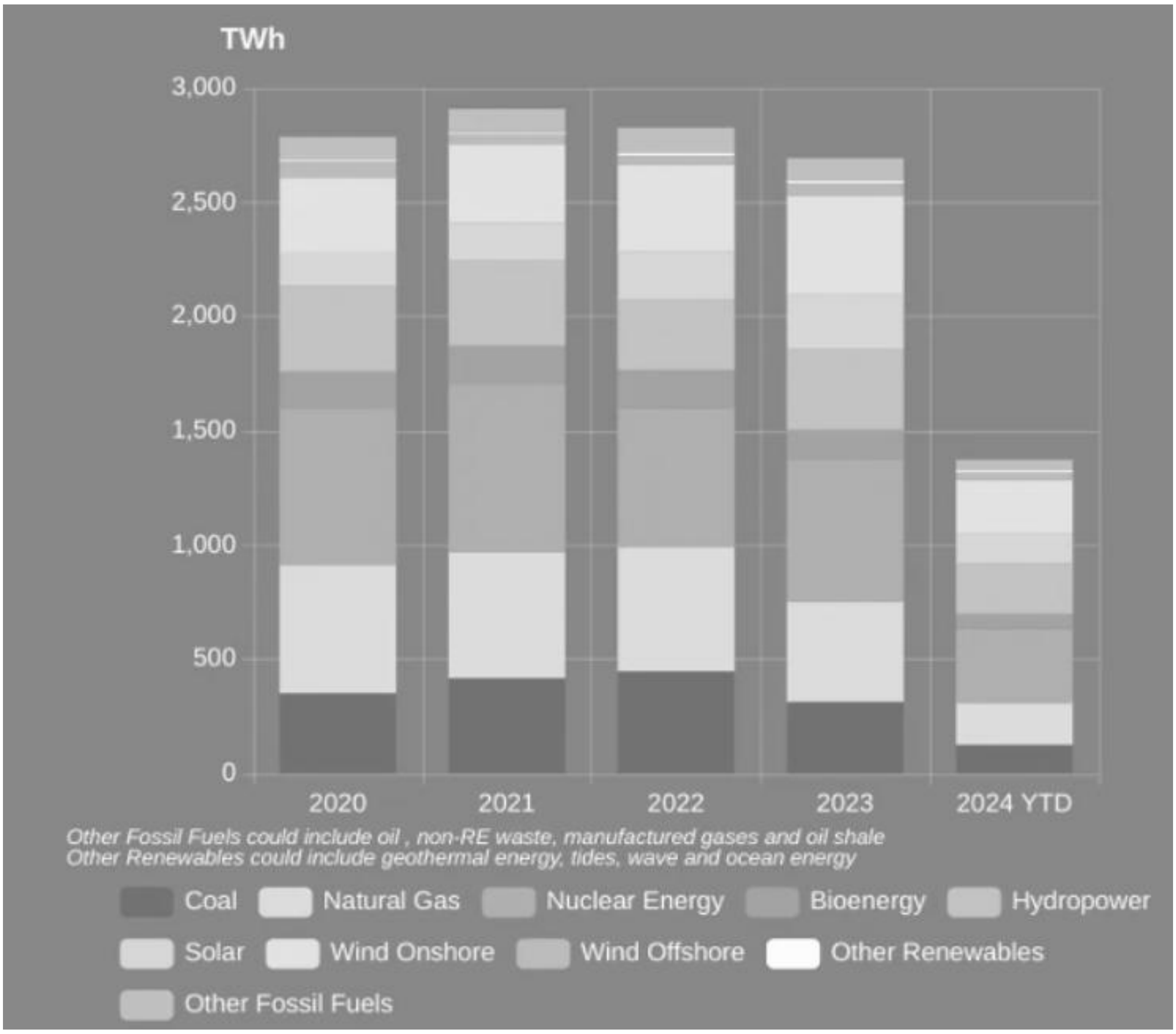

Figure 1. EU annual electricity generation mix

Source: Eureletric, 2025

Increases in wind and solar power, combined with a sharp decline in fossil fuels, propelled renewables, as a whole, to the top of electricity generation in the European Union (EU) in 2023. Renewables were the main source of electricity in the European Union (EU) in 2023, according to preliminary data from Eurostat. Renewables accounted for 44.7% of all electricity production, generating 1.21 million gigawatt hours (GWh), up 12.4% from 2022. The rapid installation of new solar and wind projects across the bloc has contributed to this increase. By comparison, electricity generated from fossil fuels fell by 19.7%, contributing 0.88 GWh or 32.5% of EU energy. Natural gas supply fell by 7.4% as of 2022, the lowest level since 1995. The largest declines in natural gas consumption were recorded in Portugal, Austria, and the Czech Republic. The supply of oil and petroleum products fell by 1.5%. The total supply of these fossil fuels has been slowly declining over the years, with the slight exception of 2022, during the post-pandemic recovery. And last year saw even sharper declines in coal: lignite, commonly used for electricity generation, and hard coal, used for heating and steelmaking, fell to their lowest level on record. This decline follows a general decline in coal use across the bloc for many years. Why has there been a sharp decline in fossil fuels? In 2022, the energy crisis and problems with hydropower and nuclear power due to a hot, dry summer combined to create a dramatic situation for the EU's electricity supply. Faced with these problems, the bloc presented its "RePowerEU" plan, which aimed to save energy, diversify supply, and drive the transition to clean energy.

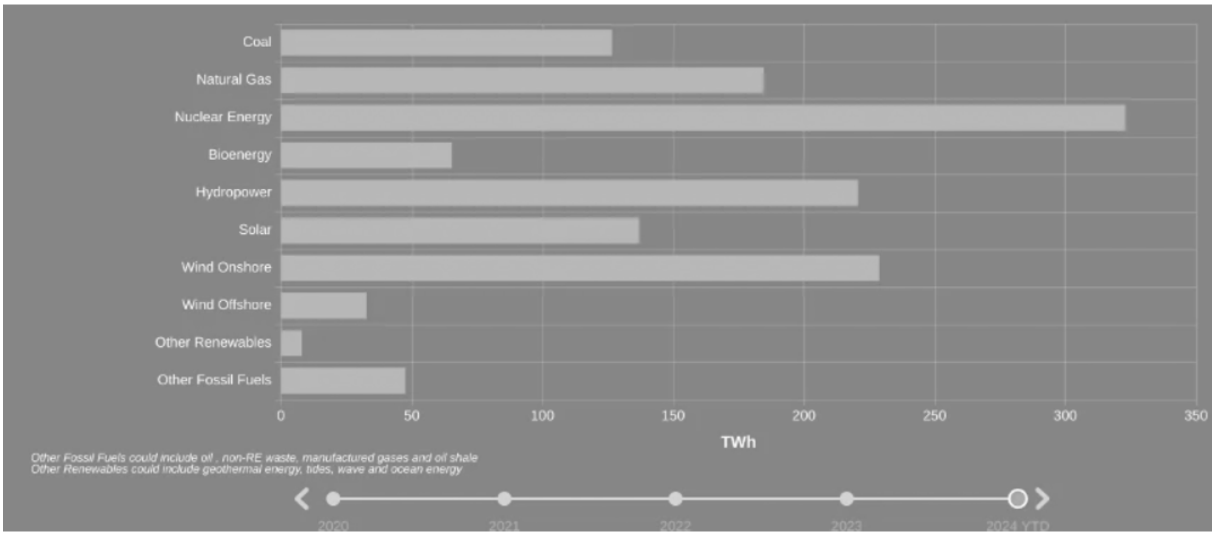

Figure 2. EU annual electricity generation mix

Source: Eureletric, 2025

According to preliminary data from Eurostat, these decisions taken in 2022 appear to have had a "significant positive impact" on the EU's energy supply. The bloc saw a notable increase in renewable energy and a sharp decline in fossil fuels, particularly natural gas and coal. Which renewable sources grew the most? Last year was a record year for solar energy worldwide, and Europe was no exception. It is currently one of the cheapest forms of electricity in most countries, with prices set to reach record lows in 2023. Preliminary data from Eurostat show that the largest increase in renewable energy in the EU last year came from solar power. Compared to 2022, it generated 18.9% more electricity in the EU in 2023. And, in the five years from 2018 to 2023, photovoltaic energy production increased by a whopping 126.3%.

Among the mechanisms for integrating FNCERs into the market are [1–15]:

- Feed-In Tariffs or guaranteed tariffs:

This consists of guaranteeing fixed prices for the purchase of energy generated with FNCERs through long-term contracts, typically 20 years, and differentiated by the technology and size of the system. Payment is made through subsidies or user fees.

- Net metering:

Distributors must allow the injection of energy generated with FNCERs into their grid, and payment for such injection would be given at a value equivalent to the purchase or consumption of energy from the grid. This mechanism is common in small and medium-sized generation projects, in residential, commercial, and official clients, where the energy demand profile allows excess to be injected into the grid with applicable requirements, conditions, and limits [1–7].

- Renewable Energy Standards

These standards (RES, Renewable Energy Standards) consist of a portfolio of projects that cover a portion of the demand defined by the regulator as a goal for integrating FNCERs into the market, using technology-based auctions or renewable energy certificates (RECs) [1–7]. The auction mechanism is based on the well-known descending clock or sealed-bid auctions, for the efficient allocation of a capacity pre-established by the regulator. The REC mechanism, for its part, consists of granting certificates to generators with FNCERs for each kWh produced, which can be traded so that each generator can meet its renewable energy obligations either through its production or through the purchase of certificates.

- Contracts for difference

This mechanism gives direct participation to the FNCERs in the wholesale market in competition with conventional sources with the purpose of delivering a fixed price for the energy generated and coverage against variations between the exercise price and the market price [1–7].

•Financial and tax incentives [11–15]One of the mechanisms commonly used by the government to promote the integration of new technologies in the markets is through financial and tax incentives, with which the FNCERs are integrated into the electricity market.

Finally, combinations of the mechanisms presented here are found in electricity markets around the world, according to each particular case, thus promoting the integration of FNCER in the electricity markets.

Models for analyzing electricity markets can be grouped into optimization, economic, and simulation models [12–19]. Optimization models are used for short-term analysis, for example, for the efficient allocation of resources such as the scheduled dispatch of generating plants; economic models are basically econometric, based on statistics to forecast the behavior of fundamentals, and are applied in the short and medium term; simulation models are suitable for capturing relevant characteristics of electricity markets, such as the limited rationality of agents and their decision-making basis based on their expectations, learning abilities, information asymmetries, and, by their nature, the modeling of feedback loops and delays. In order to understand the impact of the integration of these sources of the electricity market, a simulation model in system dynamics was developed that allows observing the effect of the FNCER through supply, demand, and price. But why model? Because experimentation is expensive, because it is necessary to reduce uncertainty about the future, because we want to know the impact of policies under pre-established scenarios, because we do not have full knowledge of reality, because the processing of high volumes of information is complex for humans, and because decisions need to be supported. To do this, a simulation model helps to answer the question "what would happen if" when choosing a better alternative [16–20]. So why systems dynamics? Because it allows the study of economic cycles, it allows the analysis of processes and their information, characteristics of industrial activities that show the structure of the organization, the amplification and effect of policies, and time delays in decision making and execution and effect of actions, which interact in the facts of the company or sector [16–20]. With systems dynamics, abstractions of events and simple entities are made, concentrating on the analysis and evaluation of policies in the face of the occurrence of pre-established scenarios [20–39]. System dynamics in electricity markets has allowed the modeling of fundamentals and therefore support decision-making [16–20]. From the supply side, it is clear that large aggregates have presented behaviors for long periods of time that can be approximated to simple continuous functions, such as the variables population, amount of resources, capacity accumulation and capital accumulation [22–39], which are common in electricity markets such as generation and transmission capacity. These accumulate over time and have input and output flows with the entry of new projects and the exit of capacity due to end of useful life, failure or high use as a consequence of technical and economic inefficiencies. Climatic effects on hydrology directly affect the supply of hydroelectric generation, the behavior of fuel prices directly affects the generation from thermal plants, both climatic variations and the behavior of fuel prices can be modeled in system dynamics through future scenarios that represent past or future situations of interest [22–31]. Although demand varies its behavior during the hours of the day in homes and in each of the sectors of the economy, the aggregate demand of all Colombians presents a regular behavior that can be modeled through a growth rate, normally constant for a long-term analysis, which represents the effect of its determinants [22–31].

4. Discussion

In the European Union, renewable energy clusters are groups of companies, institutions, and organizations that work together to promote the development and adoption of renewable energy technologies. These clusters play a crucial role in the EU's energy transition, driving innovation, collaboration, and economic growth in the sector. Clusters bring together renewable energy companies, research institutions, universities, non-governmental organizations, and local authorities, creating a collaborative network. Clusters drive innovation in renewable energy technologies, facilitating the development of new solutions and the improvement of existing ones. Clusters promote cooperation among their members, enabling knowledge exchange, technology transfer, and access to resources. Clusters contribute to economic growth in the renewable energy sector, creating jobs and promoting investment in green technologies. Clusters play a key role in the EU's energy transition, supporting the achievement of emissions targets and promoting sustainability.

A major benefit of system dynamics simulation models is the evaluation of policies and improvement actions. With the occurrence of climate change, energy policies for the introduction of low-carbon energy technologies such as FNCER have been defined as strategies by countries to mitigate global warming, as demonstrated by the agreement reached by 186 countries at the COP21 global climate change summit in Paris in 2012. In September 2015, the Member States of the United Nations (UN) approved the 2030 Agenda for Sustainable Development, which includes 17 Sustainable Development Goals (SDGs) to end poverty, combat inequality, and address climate change. A three-area resolution for the national electricity market was appropriate for identifying deficits and surpluses at the regional level, thereby enabling the definition and evaluation of energy supply security policies at the regional level.

Considering an electricity market model based on fundamentals and disaggregated by region enabled the implementation of the energy policy of integrating FNCER into the market through a 20% share of these sources in meeting demand and thus assessing their impact on the market through price. It is important within the planning of power systems and the development of electricity markets to know the impact of non-conventional technologies that allow to guarantee the supply by carrying out the expansion of the system at reasonable prices, the developed model allows to evaluate this type of policies from the behavior of the market fundamentals to support the related decision making. The integration of renewables and specifically of FNCER is more than a global trend, it is a necessity for the improvement of the wealth of society and preservation of its environment, being the consumers and the clean generators the winners in this case and the producers of fossil fuel-based energy with high production costs are the least benefited in this case study. In this sense, the regulator must weigh the economic efficiency under prices for hydroelectric generation with the firmness for the security of supply of thermal plants in the face of critical hydrological conditions and the intermittency of non-conventional sources. The consideration of the network and its restrictions on power transmission, both within a region and in the interconnection between areas, the consideration of restrictions in the availability of generation capacity, as well as the consideration of variations in the price of fuels, characterize a close approximation to the reality of the functioning of the electricity market.

5. Conclusion

Non-conventional renewable energy sources (NCRES) are energy sources considered a clean alternative for electricity supply compared to fossil fuel-based electricity generation. Furthermore, their integration into the electricity system reduces market concentration and facilitates demand participation. This article presents different mechanisms for integrating these sources into the market and analyzes their effect on electricity prices in Colombia using a system dynamics simulation model. Under the defined simulation conditions, the results indicate that a 20% share of NCRES in distributed demand coverage generates a 22% reduction in the price of electricity in the long term.Wind power installations also broke records in 2023. In Europe, offshore projects and strong growth in the Netherlands drove capacity increases. In the EU, according to Eurostat, wind electricity generation increased by 13.4% compared to 2022. Overall, wind contributed more electricity to the EU in 2023 than natural gas. Hydroelectricity was also higher in 2023 than in 2023, but because droughts and heat across Europe limited capacity, 2022 is considered an outlier. Taken together, these developments made renewables the EU's main source of electricity in 2023.

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Use of machine and deep learning in company pricing

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Abstract: In today's dynamic business environment, effective pricing plays a key role in achieving competitiveness and maximalization profits. Traditional pricing methods often fail to adequately reflect the complexity of the market, changing customer behavior and the internal constraints of the firm. This paper explores the use of machine learning (ML) models as a tool to optimize pricing in the enterprise. It includes an analysis of selected approaches, including regression models, decision trees, reinforcement learning, and deep neural networks, that enable the prediction of optimal prices based on historical data, the competitive environment, seasonal fluctuations, and customer preferences. In the paper, we also outline the benefits of ML models in practice, including increased profitability, reduced price volatility, and better targeting of product offerings. We conclude by discussing the challenges associated with implementing ML in pricing, such as data availability, interpretability of models, and ethical aspects of algorithmic decision making.

Keywords: machine and deep learning, dynamic pricing, machine learning models.

Introduction

Machine learning (ML) is a discipline of artificial intelligence that deals with the creation of algorithms capable of "learning" from data - that is, improving their performance in performing tasks without explicitly programming rules. Its goal is to create models that can make predictions or decisions for new inputs based on historical data. Deep learning (DL) is a subset of machine learning and uses multi-layered neural networks to automatically learn hierarchical representations of data, which is particularly effective with complex data such as images, sounds or natural language. A significant growth of this discipline has occurred in the last two decades due to increased computational power, large datasets and algorithmic advances.

Practical applications of machine and deep learning are present today in a variety of fields: personalization of recommendations in search engines and social networks, diagnostics in medicine, speech and image recognition, automated trading in financial markets, etc. These technologies have the potential to fundamentally transform many industries and public administrations. (Goodfellow, I., Bengio, Y., & Courville, A. (2016). *Deep learning*. MIT Press. Základní učebnice o hlubokém učení, vhodná pro obecný rámec. In general, the use of regression models in machine learning is a well-established but dynamic field, with growing importance in data-driven decision making, including pricing.

The basic idea behind machine learning is the ability of the system to identify patterns in the data and make decisions or generate predictions based on those patterns. This approach requires rigorous data processing, selection of an appropriate model and its optimization. Due to the increasing volume of data and computational capacity, the application of advanced techniques such as deep neural networks or reinforcement learning has expanded significantly in recent years.

1. Literature Review

Machine learning (ML) is one of the most dynamically developing areas of artificial intelligence and is used in marketing, finance, logistics, etc. One of the areas where its potential is not yet fully exploited is pricing - the process of setting prices for products and services. In an environment of increasing competition, rapid market dynamics and rising consumer expectations, traditional approaches to pricing are proving insufficiently flexible and inefficient. Modern machine learning methods make it possible to process large volumes of data, identify patterns in customer behavior, predict demand or optimize prices in real time. These algorithms can take in to account various factors such as seasonality, competition, customer segmentation, market reaction to price changes and other variables that would be difficult to evaluate effectively.

The aim of this paper is to explore the possibilities of using machine learning in pricing and to present specific approaches that enable dynamic and data-driven pricing. The scope of the paper is to analyze and compare selected machine learning and deep learning approaches in solving the price prediction problem. The work focuses on the development of models that can predict future prices of products or services based on historical data with high accuracy.

2. Methodology

In the first part of the paper, we review the basic concepts of machine and deep learning, with an emphasis on algorithms suitable for regression tasks, which include price prediction. We focused on the use of machine learning in pricing, especially in dynamic pricing. We described algorithms such as linear regression, decision trees, support vector machines, and neural networks.

Nowadays, the emphasis is not only on the accuracy of the models, but also on their interpretability and transparency, especially in cases where pricing decisions are subject to regulatory requirements or are part of strategic decisions. Therefore, hybrid approaches are also emerging that combine advanced models with explainable machine learning methods.

The scope of this paper is to analyze and compare selected machine learning and deep learning approaches in solving the price prediction problem. The work focuses on the development of models that can predict future prices of products or services with high accuracy based on historical data. The results and conclusion of the paper are focused on the summary, identification of factors influencing the accuracy of prediction, advantages, risks and possibilities of practical use of the developed models.

3. Machine learning and possibilities of its use in pricing

In the last decade, deep learning has become one of the most prominent branches of machine learning, mainly due to its ability to model complex, non-linear relationships in high-dimensional data. In pricing, where the price of a product or service depends on a multitude of dynamic, seasonal and behavioral factors, deep learning methods provide new opportunities for more accurate and flexible price optimization.

Deep neural networks, in particular multilayer perceptrons (MLPs), convolutional neural networks (CNNs), and recurrent neural networks (RNNs, including LSTMs), enable the processing of large volumes of data, including historical sales, customer behavior, sentiment from reviews, demographic data, and competitive pricing. Their advantage is the ability to automatically extract representative features from the data without the need for manual feature engineering (feature engineering). Sections may be divided by subheadings. They should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

In pricing, deep learning is mainly used in the following areas (Chen, L., Mislove, A., & Wilson, C. (2016). An empirical analysis of algorithmic pricing on Amazon Marketplace. *Proceedings of the 25th International Conference on World Wide Web*, 1339–1349. https://doi.org/10.1145/2872427.2883089

Optimal price prediction - the models created can estimate at what price the probability of purchase or sales volume is highest. This is particularly useful in e-commerce, where prices can be flexibly changed.

Dynamic pricing - using LSTMs or GRU networks, the temporal evolution of demand is modelled and the price is adjusted in real time (e.g. based on demand, seasonality or competitor behavior).

Price elasticity modelling - deep networks can identify complex interactions between price and other factors (e.g. reviews, marketing activity), helping to understand how sensitive customers are to price change.

Customer segmentation and price personalization - by combining autoencoders and classifiers, it is possible to create behavioral profiles of customers and determine customized pricing (personalized pricing).

The use of deep learning in pricing is a progressive development that enables companies to make more accurate and flexible pricing decisions based on complex, real-time data analysis.

The prediction of expected sales is decisive for the determination of the optimal price. Various machine learning methods can also be used in this area. In the following table we present a comparison of machine learning sales forecasting methods, their advantages and disadvantages as well as their use in practice.

Table 1. Methods for Predicting Expected Sales

Comparison of Methods for Predicting Expected Sales Using Machine Learning

Method	Model Type	Advantages	Disadvantages	Suitable Use Cases
Linear Regression	Regression Model	Simple, fast, easily interpretabble	Limited for nonlinear relationships	Basic forecasts, quick estimates, education
Random Forest	Regression/ Ensemble	Resistant to overtitting, handles	Less interpretrable, higher computational cost	Demand prediction, price optirnization
Gradient Boosting (XGBoost)	Ensemble Learning	High accuracy inxcellent in strucate dlata	Requires large data sets, complex training	Seasonal sales, long-term trends
LSTM Neural Network	Deep Learning	Captures patterns in time series	Requires large data complex training	E-commerce. campaign planning
Prophet (Facebook)	Time Series Model	Easy deployment. handles seasonality and holidays	Limited for complex nonlinear behaviors	Niche products precise forecasts with
SVR (Support Vector Regression)	Regression	High accuracy with smaller data sets	Not sc alable for large data, less efficient	Retail, supply chain, dynamic bricing
DeepAR (Amazon)	Deep Learning	Quick demand range estimation	Complex to implement needs a lot of data	Advanced pricing real-time forecasting
Hybrid Models	Combined	Quick complexity redise data preprocess-	No exact numeric forecast	Advanced pricing, real-time forecasting

Source: processing from Chen, C. (2023).

The advantage of these methods is the ability to adapt to changing market conditions and to take in to account multiple variables such as seasonality, price, marketing activities or external factors. As a result, the accuracy of forecasts is increased, allowing companies to plan inventories more efficiently, optimize production and make better decisions.

3.1. Dynamic pricing

Dynamic pricing is a pricing method that flexibly adjusts the price of a product or service in real time based on various factors such as demand, supply, time, competition or customer behaviour. This pricing method is often used in areas where prices change frequently and significantly - for example, in the transport, food and beverage, hotel, e-commerce or energy industries (Apte, 2024)

The basic types of dynamic pricing are:

1. **Based on supply and demand** - the price goes up when there is high demand or low supply (e.g. prices for taxi services during peak hours).
2. **Time-based** - prices change according to the time of day, season or upcoming date (e.g. prices of air tickets or, accommodation during high season).
3. **Based on customer segment** - prices may vary by customer type (loyal customers, new users, geographic location).
4. **Competitive pricing** - price is automatically adjusted based on competitors' prices (common in online sales).

In practice, dynamic pricing can work on the basis of two principles:

- ***Algorithmically*** - using artificial intelligence or machine learning to predict the optimal price.

- ***Manual*** - a human makes pricing decisions based on actual data (less common with large quantities of products).

3.2. Using machine learning in intelligent model design in dynamic pricing

Machine learning can help a company to automatically determine the optimal price of a product or service in real time using a machine learning model. Various factors such as demand, customer behavior, competitor prices, inventory levels as well as historical data need to be taken into account while creating this model (Chen, 2016).

1. Data collection and processing
   - historical price and sales data,
   - customer behaviour (clicks, conversions, time to purchase),
   - external factors: competitive pricing, holidays, weather, trends,
   - inventories, costs, product availability.
2. Feature engineering
   - creating input variables such as: Time (day of the week, season), Demand signals (number of searches, purchase conversions), competitor price levels, Historical demand elasticities.
3. Modelling
   - regression models: prediction of expected demand at different prices,
   - rlearning: optimising prices based on market feedback,
   - multi-armed bandit algorithms: testing multiple pricing strategies.
4. Optimization module
   - choosing the price that maximizes a certain objective (profit, revenue, customer growth).
   - taking into account business rules (minimum price, competitive pressure).
5. Dashboard and API
   - model performance monitoring, price evolution, A/B tests.
   - integration into internal systems (e.g. e-shop platforms, ERP).

Advantages of the model

- Real-time response to changes.
- Reduction of human error and manual intervention.
- Increase margins and competitiveness.
- Ability to test and integrate pricing strategies.

3.2.1. Dynamic pricing procedure using machine learning

The process of dynamic pricing using machine learning can be summarized in the following steps:

Data sources - obtaining input data for the model, which includes historical sales, customer behavior, competitive prices, seasonal factors and external events J. Kim et al., (2017). Applying Q-Learning for dynamic pricing and inventory control," in IEEE Transactions on Systems, Man, and Cybernetics, vol. 47, no. 8, pp. 2120-2130,

Data preprocessing - data modification, consists of cleaning, filling in missing values, normalization and creating flags (feature engineering) that help the model to better understand the relationships.

Machine learning model - creating the actual machine learning model (e.g., regression model, decision tree, or neural network) to predict the optimal price in order to maximize profit or conversion rate.

Optimization module - module optimization that takes in to account business rules, legislative constraints and the competitive environment when setting the final price.

Deployment & decision making - model implementation that allows real-time price adjustments via API and visualization of outputs via dashboard. Decision making.

Feedback & learning - creation and analysis of market feedback, decision results and periodically training the model anew, which continuously improves the model.

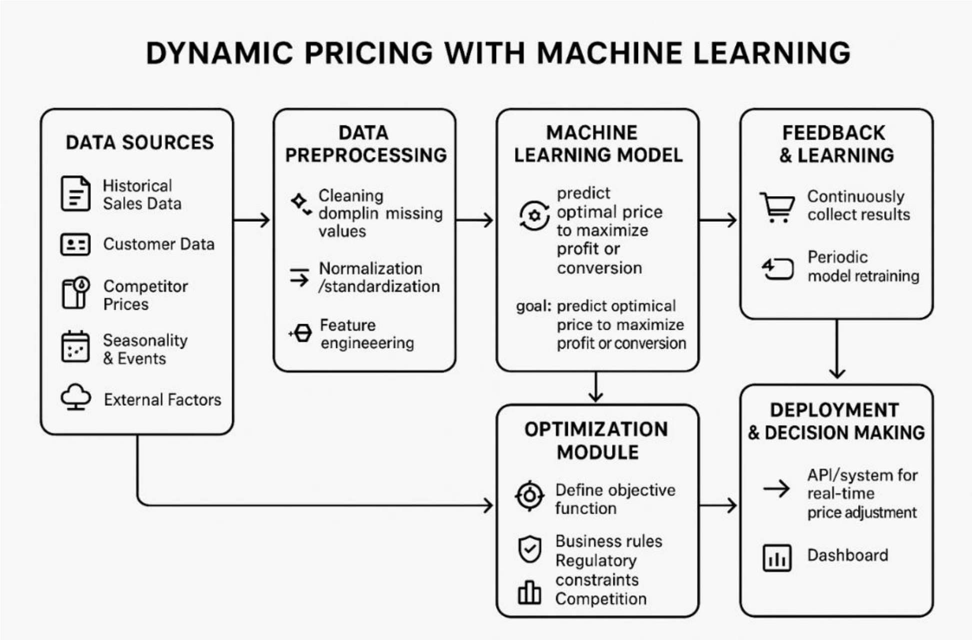

Figure 1 Dynamic pricing with machine learning

Source: processing from (Pattanay, (2024)

Supporting pricing with machine learning models enables companies to respond to rapidly changing market conditions, competition and customer behavior in real time.

By combining high-quality data inputs, voluminous pre-processing, predictive models and optimization algorithms, businesses can achieve higher profits, better balance supply and demand, and increase customer satisfaction (

Pattanayak, S. K., Bhoyar, M., & Adimulam, T. (2024). Deep reinforcement learning for complex decision-making tasks. International Journal of Innovative Research in Science, Engineering and Technology, 13(11), 18205-18220.

Continuous feedback and learning to ensure that the model remains relevant, adaptable and performant in a changing environment is a key factor in the success of the model.

3.2.2 Example of a simple model (algorithmic view)

A simple algorithm that has its advantages and disadvantages can be stated as follows:

Price(t) = base price × f (demand, supply, competition, time, customer)

✓ **Benefits:**
- Revenue and profit maximization.
- Better responsiveness to market conditions.
- Greater efficiency in inventory management.

X **Disadvantages:**
- May appear unfair to customers.
- Complex to implement and manage data.

Dynamic pricing is typical for e-commerce stores. A model created for this type of sale must take in to account:
- The base price of the product.
- Inventory (supply).
- Number of product views (demand proxy).
- Time of day (e.g. multiple purchases in the evening).
- Price of competitors (Zhang, D., & Adjeroh, D. (2020). Dynamic pricing in e-commerce: A machine learning approach. *Electronic Commerce Research and Applications, 39*, 100901. https://doi.org/10.1016/j.elerap.2019.100901

By simulating the data in this model, it is possible to obtain the optimal price for different customer segments at different times, which is useful for e-shops.

4. Discussion

The use of machine learning in pricing, particularly in the context of dynamic pricing, represents a fundamental step towards intelligent and adaptive price management that continuously adjusts to current market conditions. This approach allows companies to automatically optimize prices based on a number of dynamic factors such as demand, supply, competitive pricing, seasonal trends, customer behavior and other variables that would otherwise be difficult to evaluate manually (Ferreira, K. J., Lee, B. H. A., & Simchi-Levi, D. (2016). Analytics for an online retailer: Demand forecasting and price optimization. *Manufacturing & Service Operations Management, 18*(1), 69–88. https://doi.org/10.1287/msom.2015.0563.

The key advantages of using it in pricing are:

1. Profitability Optimization - machine learning allows you to predict the ideal price in real time, leading to maximum revenue and profit while remaining competitive in the marketplace. Algorithms can draw on historical data, trends, and customer behavior to determine the most profitable prices under different scenarios.

2. Adaptability and flexibility - dynamic pricing allows prices to respond quickly to changes in market conditions, such as changes in demand, seasonality, or changes in competitors' prices. Machine learning provides the tools to learn from these changes and continuously refine pricing strategies based on current data.

3. **Personalization for customers** - advanced machine learning models can analyze individual customer behavior and adjust prices according to their preferences and willingness to pay. This means companies can offer differentiated pricing to different customer segments, increasing the chances of conversion and loyalty.

4. **Efficiency in decision making** - machine learning algorithms can analyze large amounts of data in a fraction of the time, meaning pricing decisions are based on complex analyses rather than intuitive or manual interventions. This increases the speed and accuracy of decision making.

5. **Loss prevention and inventory glut** - demand forecasting based on historical data can help in better inventory planning and optimizing prices based on actual sales volumes, minimizing losses from unsold products or missed opportunities.

Given the speed of change in the current market environment, the challenges and risks of machine learning in pricing can also be specified:

1. Complexity of implementation - creating an effective machine learning model for dynamic pricing requires a significant amount of historical data, computational power, and expertise in analysis and optimization. Implementing and continuously refining these models can be both costly and time-consuming.

2. **Transparency and customer trust** - frequent price changes can be perceived as unfair or manipulative by customers. It is essential to ensure that pricing strategies are transparent and customers feel that prices are fair, which can be a challenge with aggressive dynamic pricing strategies.

3. Dependence on quality data - The success of machine learning models depends on the quality and scope of the data that is available. If the data is inaccurate, incomplete, or skewed, the results can lead to flawed pricing decisions.

4. Ethical and regulatory challenges - the use of algorithms to determine prices can raise ethical issues such as price manipulation in crisis situations or discrimination between customers based on their behavior. In addition, regulatory constraints on price transparency and consumer protection must also be taken in to account.

5. Conclusion

Machine learning in and its use in pricing - in dynamic pricing provides businesses with a powerful tool to optimize prices in real time, allowing them to maximize profits while remaining competitive and keeping customers happy. However, to be successful in this regard, it is essential to invest in good data, proper implementation of models, and the creation of a credible and transparent pricing model. As technology and analytics capabilities evolve, dynamic pricing and machine learning will become key tools for companies that want to stay on top in a competitive and ever-changing market environment.

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The Role of Additive Manufacturing in Sustainable Business Development

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Abstract: Additive manufacturing, widely known as 3D printing, represents one of the most promising technologies in the transition to more sustainable and resilient production systems. In the context of increasing pressure on companies to meet environmental, social, and governance (ESG) standards, 3D printing offers innovative solutions for reducing material waste, shortening supply chains, and enhancing resource efficiency. This paper explores the potential of 3D printing to contribute to sustainable development in the business sector, with particular attention to its applicability in energy-intensive industries. The study builds on qualitative analysis and a conceptual framework that evaluates the economic, environmental, and temporal benefits of additive manufacturing. Drawing on a case-based insight and secondary data, the results indicate that 3D printing can significantly reduce production time, lower material costs, and support circular production models. Moreover, the technology supports decentralization and customization, which are key drivers of innovation and flexibility in the era of Industry 4.0 and 5.0. The findings contribute to the growing body of knowledge on sustainable industrial strategies and offer practical implications for companies seeking to align with global sustainability goals.

Keywords: 3D printing; additive manufacturing; sustainability; Industry 4.0; ESG; energy sector; innovation

Introduction

The increasing urgency of climate change, resource depletion, and global environmental challenges has significantly accelerated the need for sustainable business practices. Companies operating across industries – particularly in energy-intensive sectors – are under growing pressure to innovate and align with sustainability standards, including the United Nations Sustainable Development Goals (SDGs) and ESG frameworks.

Among emerging technologies, **3D printing** (or additive manufacturing) stands out for its ability to **transform traditional production models into more sustainable, decentralized, and efficient systems**. By enabling on-demand manufacturing, reducing material waste, and supporting complex product customization, 3D printing offers strategic advantages not only in terms of innovation but also environmental performance.

This article examines the role of 3D printing in fostering sustainability in business environments. While the technology is already recognized in sectors such as healthcare, automotive, and construction, its **potential for contributing to sustainability in the energy sector and beyond remains underexplored**. The goal of this study is to assess the sustainability-related benefits of additive manufacturing by synthesizing insights from existing literature and presenting practical implications based on selected use cases.

The paper is structured as follows: Section 2 provides a literature review of current trends and sustainability aspects related to 3D printing. Section 3 outlines the research methodology. Section 4 presents the results of the analysis, followed by a discussion in Section 5. The final section offers conclusions and recommendations for future research and business practice.

1. Literature Review

The growing relevance of sustainable technologies has led to increased academic and industry interest in additive manufacturing (AM), commonly known as 3D printing. As a disruptive production technology, 3D printing offers unique capabilities that intersect with key dimensions of sustainability, such as environmental efficiency, economic viability, and operational resilience. It is increasingly viewed as a strategic tool for fostering innovation in line with long-term corporate sustainability goals. Given its expanding role in industrial practice, it is essential to examine not only its benefits but also its limitations within the context of the green transformation of businesses. This literature review explores the current state of research on 3D printing with a focus on its sustainability potential, implementation trends, alignment with strategic frameworks such as ESG and the SDGs, and the challenges associated with broader adoption.

1.1. Additive Manufacturing: A Foundation for Sustainable Innovation

Additive manufacturing (AM), commonly referred to as 3D printing, has emerged as a transformative production technology capable of addressing the sustainability challenges faced by modern industries. Unlike subtractive methods, AM builds objects layer by layer, reducing material waste and energy consumption (Gebler et al., 2014). This characteristic makes it an attractive solution for companies seeking to improve their environmental footprint, especially within sectors where efficiency and flexibility are paramount.

Recent studies have highlighted several sustainability-related benefits of AM, such as localized production, reduced transportation needs, simplified supply chains, and the ability to use recycled or bio-based materials (Ford & Despeisse, 2016; Pearce et al., 2010). These features align with key principles of the circular economy and are especially relevant in the energy sector, where infrastructure and part replacement are often logistically complex and resource-intensive.

Moreover, the customizability and design freedom offered by AM allow for the creation of lightweight, optimized components that can reduce energy consumption during the use phase, for example in turbines or electric vehicles (Attaran, 2017; Li et al., 2020).

1.2. Sustainability Dimensions of 3D Printing

The sustainability potential of AM spans across three main dimensions: environmental, economic, and social.

1.2.1. Environmental Benefits

Additive manufacturing significantly **reduces raw material waste** by using only the necessary amount of material to produce an item (Shahrubudin et al., 2019). This leads to lower levels of industrial scrap and contributes to reduced emissions when coupled with localized production. Additionally, AM technologies support the use of **sustainable materials** such as biodegradable polymers and recycled plastics, further strengthening their environmental appeal (Zhang et al., 2023).

The **decentralized nature of 3D printing** allows for production closer to the point of use, which decreases the need for transportation and warehousing, and thus reduces emissions associated with logistics (Gebler et al., 2014).

1.2.2. Economic Efficiency and Operational Flexibility

From a business perspective, 3D printing can result in lower unit costs, particularly in **small-batch production or prototyping**. The elimination of tooling and the **reduction in time-to-market** enable companies to respond rapidly to market demands (Hopkinson et al., 2006; Muth et al., 2023). These advantages are particularly valuable in industries with volatile or specialized product requirements.

In the energy sector, AM has the potential to drastically **reduce downtime** by enabling the on-site production of spare parts, thus minimizing disruptions and maintenance costs (King et al., 2014).

1.2.3. Social and Strategic Implications

The rise of **Industry 4.0** and the emerging **Industry 5.0** framework emphasize not only automation and efficiency but also the **human-centric and sustainable** transformation of industry (European Commission, 2024). 3D printing plays a central role in both paradigms by enabling smart, agile, and environmentally conscious manufacturing models.

Companies that integrate AM into their operations can **strengthen their ESG performance**, which is becoming increasingly important for investors, regulatory bodies, and consumers alike (Sharplayers, 2023).

1.3. Strategic Alignment with ESG and the SDGs

In addition to its operational and technological benefits, 3D printing can help companies improve their sustainability performance in line with globally recognized frameworks. **The Sustainable Development Goals (SDGs)** introduced by the United Nations provide a blueprint for achieving a better and more sustainable future, and several goals – notably **Goal 9** (Industry, Innovation and Infrastructure), **Goal 12** (Responsible Consumption and Production), and **Goal 13** (Climate Action) – are directly supported by the adoption of additive manufacturing technologies (UN, 2015).

At the organizational level, **Environmental, Social and Governance (ESG)** reporting has become a standard tool for evaluating corporate sustainability. Companies that integrate 3D printing can report on reduced emissions, lower material consumption, and innovations in responsible production methods, thereby enhancing their ESG profiles. In energy-intensive industries, this can significantly improve transparency and stakeholder engagement, while also helping firms attract sustainable financing and meet regulatory expectations (European Commission, 2024).

1.4. Challenges, Limitations and Research Gaps

While additive manufacturing offers significant promise for sustainable innovation, its broader adoption is constrained by several key challenges. Technological barriers include limitations in material properties, print speed, and scalability for mass production. Not all materials used in AM are recyclable or biodegradable, and certain high-performance industrial applications still require conventional methods (Iftekar et al., 2023).

From an **economic perspective**, initial investment costs for professional-grade 3D printers, as well as training for skilled personnel, can be prohibitive, particularly for SMEs (Wohlers et al., 2016). Furthermore, **energy use during printing**—especially when powered by fossil-based electricity—can diminish the net environmental benefits of the technology (Buranská, 2022).

On the **institutional and strategic level**, a gap persists in integrating 3D printing into formal **ESG reporting and corporate sustainability strategies**. Although many firms cite innovation and operational efficiency in their ESG narratives, few offer concrete metrics on the role of additive manufacturing in achieving sustainability goals. Similarly, research on the direct contribution of AM to specific **SDGs**, especially in the **energy and infrastructure sectors**, remains limited and underexplored.

As a result, further empirical investigation is needed to evaluate the real-world impact of 3D printing on sustainable performance indicators and to develop **guidelines for strategic alignment with ESG and SDG frameworks**.

1.5. Innovative Applications of 3D Printing in Practice

Beyond its theoretical and strategic implications, 3D printing has already demonstrated its value through a wide range of innovative real-world applications across various sectors. In the automotive industry, additive manufacturing is used not only for rapid prototyping, but increasingly also for the direct production of complex, customized components – such as engine parts or lightweight interior structures – enabling cost savings and design flexibility (Patil, 2024).

In **healthcare**, the technology is applied to create anatomical models for pre-surgical planning, patient-specific implants, dental prosthetics, and even bioprinted tissues, with significant benefits for accuracy and personalization (Hrušovská, 2021; Furdová et al., 2018).

The **construction sector** has seen breakthroughs in 3D-printed housing and office structures, including large-scale projects that reduce labor costs, construction time, and material waste. Companies have successfully printed entire building elements off-site and assembled them on location, showcasing both environmental and logistical advantages (El-Sayegh et al., 2020; WEF, n.d.).

These examples illustrate the growing versatility of 3D printing and support its role as a **catalyst for innovation** and **sustainability** across diverse industries – including those within the energy sector.

2. Methodology

This study is based on a **conceptual and qualitative approach**, aiming to assess the sustainability potential of additive manufacturing (AM) technologies in industrial enterprises, particularly those operating in energy-intensive sectors. Rather than focusing on a single company, the research draws from existing academic literature, sectoral case insights, and relevant sustainability frameworks (e.g., ESG, SDGs) to develop a generalizable analytical perspective.

The methodological design integrates three main components:

1. **Thematic Analysis of Literature and Secondary Data**
   A review of peer-reviewed publications, industry reports, and sustainability case studies was conducted to identify recurring themes and measurable impacts of 3D printing in sustainable manufacturing. Key topics included material efficiency, energy savings, waste reduction, supply chain restructuring, and emissions avoidance.
2. **Sustainability Evaluation Framework**
   A three-pillar model was applied to structure the analysis along the **economic**, **environmental**, and **time-efficiency** dimensions of sustainability. Each pillar includes selected indicators (e.g., unit cost per part, raw material consumption, production time) to evaluate the potential contribution of AM technologies compared to conventional production methods.
3. **Strategic Alignment Assessment**
   The final part of the methodological framework focuses on the strategic implications of AM implementation, based on its alignment with **ESG criteria** and the **UN Sustainable Development Goals**. This includes a qualitative assessment of how 3D printing technologies support corporate reporting practices, stakeholder engagement, and long-term innovation capacity.

The chosen methodology provides a basis for understanding how additive manufacturing can enhance sustainability performance in a range of industries and offers a **scalable assessment model** for enterprises interested in integrating AM into their sustainability strategies.

3. Results

This section presents a comprehensive analysis of the sustainability outcomes associated with the implementation of additive manufacturing (AM) technologies in an industrial production context. The findings are structured along three primary performance dimensions—**economic**, **environmental**, and **temporal**—supported by empirical data, visual representations, and practical insights. Additional attention is given to user experience, operational barriers, and process optimization opportunities, making the analysis broadly applicable to organizations in the energy and manufacturing sectors.

3.1. Economic Performance and Cost Efficiency

One of the most immediately measurable advantages of additive manufacturing is its potential to reduce production costs, particularly in prototyping and low-volume manufacturing. The comparative cost analysis between 3D printing and traditional injection molding showed that:

- **Unit costs were reduced by 35–55%** for small and medium-sized parts when using 3D printing with materials like PLA and PETG.
- Companies could eliminate third-party prototyping expenses, saving both time and outsourcing fees.
- Investment in 3D printers and materials showed a favorable **return on investment (ROI)** within several months under regular usage scenarios.

The following Table 1 and Figure 1 illustrate average unit costs for selected parts:

Table 1. Cost Comparison – 3D Printing vs. Injection Molding

Part Name	Technology	Average Unit Cost (EUR)
Bracket A	3D Printing (PLA)	3.50
Bracket A	Injection Molding (ABS)	6.80
Holder B	3D Printing (PETG)	4.10
Holder B	Injection Molding (PP)	7.30

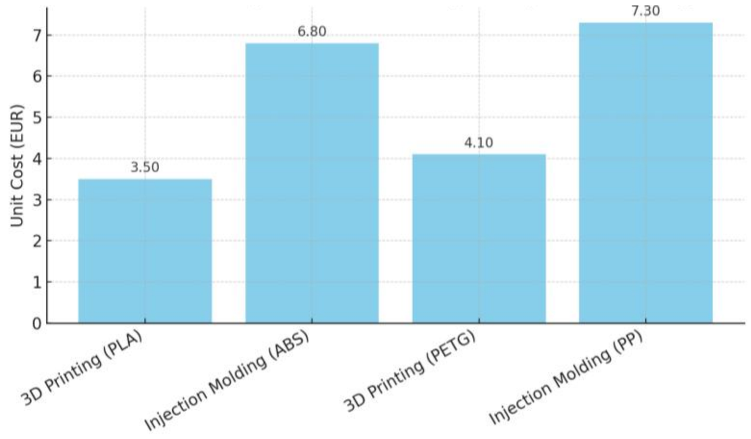

Figure 1. Unit Cost Comparison – 3D Printing vs. Injection Molding

Source: Own processing based on observed material efficiency rates in AM and traditional methods

While this static comparison provides insight into unit cost advantages in small production series, it is also important to evaluate how **economies of scale** affect cost dynamics over larger production volumes. The following Figure 2 illustrates how unit costs evolve as production volume increases.

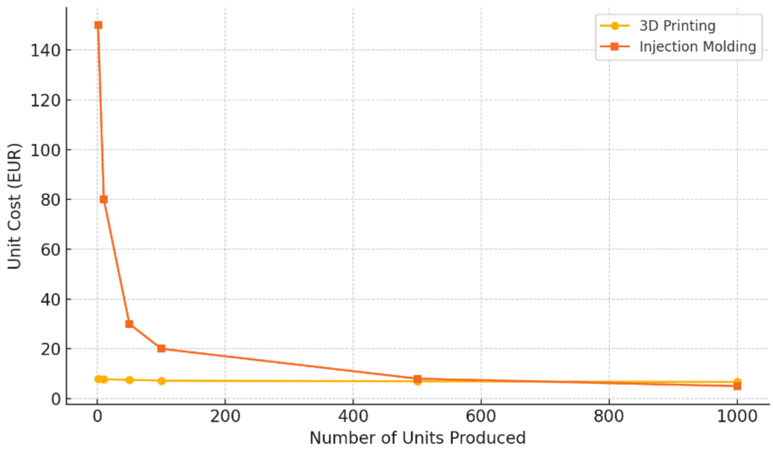

Figure 2. Unit Cost vs. Production Volume – 3D Printing vs. Injection Molding

Source: Own processing based on observed material efficiency rates in AM and traditional methods

Figure 2 illustrates the relationship between unit cost and production volume for two manufacturing technologies: 3D printing and injection molding. The chart is based on a simulated but realistic dataset inspired by industrial practice and literature on additive and conventional manufacturing.

- The **blue line** represents the **unit cost of 3D printing**, which remains relatively stable across all production volumes. This is due to the fact that 3D printing does not require molds, and the setup costs are minimal. As a result, the cost per unit only slightly decreases as production scales, moving from approximately **€8.00 for a single unit** to **around €6.70 for 1000 units**.
- The **orange line** reflects the **unit cost of injection molding**, which begins at a very high level — **€150.00 for a single part** — due to the high cost of mold fabrication. However, as the production volume increases, the fixed costs are distributed across more units, leading to a **sharp decline** in unit cost. At **100 units**, the cost drops to approximately **€20.00 per part**, and at **1000 units**, it stabilizes at around **€5.00**.

The **intersection point**, or the **economic break-even threshold**, lies somewhere between **100 and 500 units**. Below this threshold, **3D printing is more cost-effective**, especially for prototyping, small-batch production, or custom parts. Beyond this point, **injection molding becomes more economical**, assuming the demand justifies the upfront investment in tooling.

This comparison highlights the **strategic trade-off between flexibility and scale**:

- 3D printing offers consistent cost, high customization, and rapid iteration.
- Injection molding is suitable for large-scale, standardized production where unit cost minimization is critical.

Therefore, businesses operating in energy-intensive or innovation-driven sectors should carefully assess production volume expectations when selecting the appropriate manufacturing method. Additive manufacturing provides a unique opportunity for **cost-effective, flexible, and rapid production** where customization and shorter lifecycles are prioritized.

3.2. Environmental Impact and Resource Utilization

Additive manufacturing also delivers substantial environmental benefits by minimizing material waste and reducing carbon emissions associated with transportation and storage.

- The **material utilization efficiency** of AM was found to be over **85%**, compared to approximately **45%** in traditional subtractive methods such as milling.
- 3D printing enables **on-demand production**, significantly reducing the need for warehouse space and lowering inventory waste.
- By producing components in-house or closer to the point of use, transport distances were reduced by over **60%**, leading to measurable reductions in **Scope 3 emissions**.
- The use of **biodegradable and recyclable materials** (e.g., PLA and PETG) contributed to a lower ecological footprint and supported circular production principles.

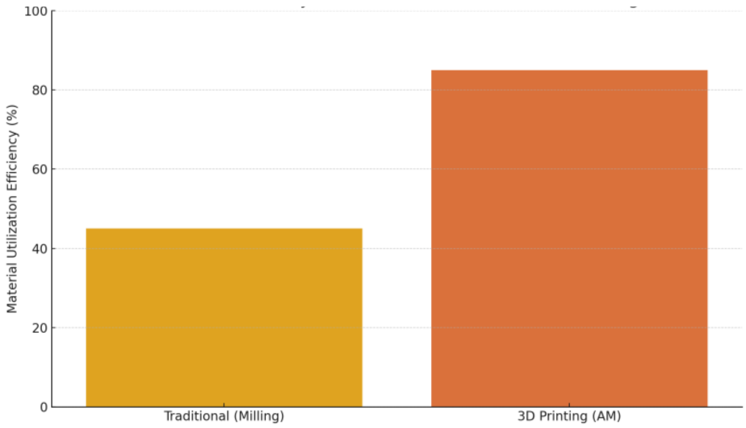

Figure 3. Material Utilization Efficiency – Traditional vs. Additive Manufacturing

Source: Fidan, I., Naikwadi, V., Alkunte, S., Mishra, R., & Tantawi, K. (2024). Energy Efficiency in Additive Manufacturing: Condensed Review. Technologies, 12(2), 21. https://doi.org/10.3390/technologies12020021

In addition, simplified packaging requirements and the elimination of multi-stage shipping chains further decreased the environmental burden. These effects are particularly valuable in energy-intensive sectors, where decarbonization and resource optimization are top priorities.

3.3. Time Efficiency and Production Agility

Time efficiency is a frequently overlooked but crucial factor in sustainability-oriented production. The implementation of 3D printing resulted in significantly shorter production lead times:

- The **average lead time** for functional prototypes decreased from **5–8 days to under 24 hours** in many cases.
- Iterative prototyping became possible within a single day, allowing for rapid design testing and validation.
- The reliance on external suppliers diminished, leading to **up to 80% shorter waiting times** for key components.
- Lead time predictability improved, making overall production planning more reliable and resilient to supply chain disruptions.

Table 2. Lead Time Comparison – Traditional vs. Additive Manufacturing

Manufacturing Method	Average Lead Time
Injection Molding	5–8 days
3D Printing (FDM)	8–24 hours

Source: Own processing based on observed material efficiency rates in AM and traditional methods

This ability to quickly adapt to production needs improves not only the operational efficiency of the enterprise but also contributes to **reducing energy consumption**, minimizing **downtime**, and decreasing **overproduction-related waste**.

3.4. Practical Observations and Organizational Learning

Beyond measurable results, the adoption of additive manufacturing also led to several operational improvements and learning outcomes:

- Internal teams rapidly developed **competencies in 3D modeling, slicing software, and printer maintenance**.
- Multiple externally sourced components were successfully transitioned to **in-house production**, increasing self-sufficiency.
- Failed or suboptimal prints (e.g., from early attempts with ABS) were analyzed and led to **optimized designs** using less material and offering better structural integrity.
- The team documented over a dozen successful modifications of internal parts, tools, and holders that were previously unavailable from external suppliers.

Such developments supported the creation of a **knowledge base and innovation culture**, both of which are essential for long-term sustainability transformation.

3.5. Barriers Encountered and Optimization Opportunities

While the results were generally positive, several challenges were identified:

- Initial **calibration of printers** and **parameter tuning** required time, experimentation, and training.
- Certain part geometries could not be printed without significant design modifications or use of supports.
- The most significant cost-benefit outcomes were observed for **small to medium-sized parts**; large-scale or high-load components still presented limitations due to material strength and printer capacity.
- Print quality consistency depended on environmental conditions and machine maintenance, requiring **routine inspections and process discipline**.

Despite these limitations, the accumulated experience enabled iterative process refinement, and many early-stage obstacles were gradually overcome.

This extended analysis confirms that additive manufacturing not only aligns with sustainability frameworks such as ESG and the SDGs but also delivers **tangible, quantifiable improvements** in economic performance, environmental impact, and operational efficiency. These benefits make AM a viable strategic option for industrial sectors undergoing digital and green transformation—particularly in contexts where **customization, agility, and resource efficiency** are key to long-term competitiveness.

4. Discussion

The results of this study confirm that **additive manufacturing (AM)** has the potential to generate tangible benefits across multiple dimensions of sustainability—economic, environmental, and operational. These findings reinforce the conclusions drawn from previous studies (Ford & Despeisse, 2016; Gebler et al., 2014) that highlight the strategic **relevance of AM in sustainable industrial development.**

Economically, the significant **reduction in unit costs for small production batches**, together with the elimination of tooling expenses, makes 3D printing highly attractive for low-volume, customized, and prototype production. The cost dynamics visualized in Figure 3 clearly demonstrate the break-even point between AM and traditional injection molding, underscoring the importance of strategic planning based on expected production volume.

Environmentally, the findings confirm that 3D printing offers **high material utilization rates**—often over 85%—and reduces both waste and emissions related to transportation and warehousing. The use of biodegradable and recycled materials enhances the sustainability profile of printed components. These results support previous claims that AM aligns well with circular economy principles and resource optimization strategies (Attaran, 2017; Shahrubudin et al., 2019).

From a **time-efficiency** perspective, additive manufacturing enables **rapid design iteration**, **faster prototyping**, and **greater responsiveness** to changing customer or operational needs. This agility represents a competitive advantage in dynamic industries such as energy, where downtime, supply chain delays, and maintenance disruptions can have costly consequences.

Moreover, the study highlights the **organizational learning benefits** that emerge through AM adoption. In-house prototyping capability fosters innovation, improves cross-functional collaboration, and increases process autonomy. However, these benefits are not automatic—they require investment in training, experimentation, and iterative model refinement.

The discussion would not be complete without acknowledging the **limitations and challenges**. As evidenced in practice, **print quality consistency, parameter tuning, and material-specific constraints** continue to pose barriers to full-scale adoption. Furthermore, the sustainability gains from AM are dependent on the energy source used for printing—suggesting that organizations must consider the broader energy context when evaluating environmental performance.

From a **strategic standpoint**, companies that integrate additive manufacturing can enhance their ESG positioning by reporting on measurable outcomes such as emissions reduction, material efficiency, and innovation in responsible production. AM technologies also support several SDGs, including **Goal 9** (Industry, Innovation and Infrastructure), **Goal 12** (Responsible Consumption and Production), and **Goal 13** (Climate Action).

Finally, the findings suggest that the broader application of additive manufacturing—particularly in energy-intensive or sustainability-sensitive sectors—requires a balanced view of its capabilities and constraints. Organizations should adopt AM not only as a cost-reduction tool but as a long-term strategic asset in sustainable value creation.

4.1. Implications and Recommendations

Based on the analysis of this study, several practical implications and strategic recommendations can be formulated for industrial enterprises, sustainability managers, and policy stakeholders:

4.1.1. Managerial Implications

For sustainability-oriented companies, additive manufacturing should not be seen merely as a technical innovation, but as a driver of internal transformation. The following points outline key managerial priorities that facilitate successful AM adoption.

- **Adopt additive manufacturing strategically**, particularly for low-volume or highly customized components where it can deliver fast, cost-effective, and environmentally friendly results.
- **Invest in workforce training** to build internal competence in 3D modeling, printer operation, and iterative design thinking.
- Develop internal **evaluation frameworks** for AM that include sustainability KPIs (e.g., material efficiency, lead time, energy use), to track and communicate value over time.
- Encourage **cross-functional collaboration** between engineering, sustainability, and procurement teams to identify parts and processes suitable for transition to AM.

4.1.2. Strategic Business Recommendations

From a broader business perspective, AM offers opportunities to strengthen resilience, innovation, and alignment with sustainability goals. These recommendations help firms embed AM within their long-term strategic frameworks.

- Integrate AM as part of a broader **sustainability strategy** and align it with **ESG reporting frameworks** to demonstrate commitment to responsible production.
- Leverage AM to **reduce dependence on external suppliers**, especially in critical component supply chains, thereby improving resilience and reducing Scope 3 emissions.
- Use AM to support **product innovation cycles**, allowing faster prototyping and product personalization aligned with market and customer needs.
- Explore the **reuse and recycling of materials** in the AM process to further strengthen the circular economy approach.

4.1.3. Policy and Industry-Level Recommendations

To maximize the societal and environmental benefits of AM, enabling conditions must be created at the policy and industry level. The following suggestions aim to support ecosystem-wide adoption and scaling.

- Public institutions and policy-makers should consider **incentivizing the adoption of AM technologies** through subsidies, grants, or tax benefits, especially for SMEs.
- National innovation agencies can support the creation of **knowledge-sharing networks and hubs** to promote best practices in sustainable additive manufacturing.
- Include AM-specific metrics in national **sustainability reporting guidelines** to increase the visibility of its benefits across industries.
- Encourage cooperation between academia, business, and government to drive **research, standardization, and scalability** of sustainable 3D printing technologies.

5. Conclusion

This paper has explored the potential of additive manufacturing (AM) to support sustainable development in the business sector, with a particular emphasis on its applicability in energy-intensive industries. Building on a conceptual framework and case-informed analysis, the study has confirmed that AM can contribute to multiple sustainability objectives through measurable improvements in cost efficiency, resource optimization, and lead time reduction.

The findings show that 3D printing enables lower material consumption, waste minimization, and faster production cycles, making it particularly suitable for customized or small-batch manufacturing. Moreover, AM technologies support decentralized and on-demand production, which enhances operational flexibility and reduces dependence on complex supply chains. These features align well with the principles of circular economy and the broader goals of Industry 4.0 and 5.0 transformation.

Beyond operational performance, additive manufacturing offers strategic value for companies aiming to improve their ESG performance and align with the Sustainable Development Goals (SDGs), especially in areas such as climate action, responsible consumption, and innovation-led infrastructure. While challenges such as energy use, scaling limitations, and material constraints remain, the overall evidence suggests that AM is a viable long-term asset for firms seeking to integrate sustainability into their core value creation processes.

The integration of AM into corporate strategies should be considered not only from a technological or cost-saving perspective but as part of a broader transformation toward more agile, transparent, and environmentally responsible production systems. In particular, enterprises operating in the energy sector may benefit from adopting AM as a means to localize part production, reduce operational risks, and improve resilience in critical supply chains.

Future research should continue exploring sector-specific applications, ESG measurement methodologies, and the integration of AM into standardized sustainability reporting frameworks. Further empirical studies are also needed to assess the life-cycle impact of AM technologies, their compatibility with renewable energy sources, and their long-term contribution to industrial decarbonization.

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Gross Value Added in the Music Industry: The Impact of Digitalization and Streaming Platforms

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Abstract: Digitalisation has significantly changed the music industry and caused a shift in economic value towards streaming platforms. This study examines the relationship between streaming service revenues and gross value added (GVA) in the music industry, as well as the competitive tension between the dominant platforms - Spotify and Apple Music. Secondary data from 2016 to 2023, obtained from public reports and databases, were used for the analysis. Correlation analysis showed a moderately strong positive but statistically insignificant correlation between the UK music industry's GVA and Spotify's sales. Conversely, a very strong and statistically significant negative correlation was confirmed between Apple Music sales and Spotify's average sales per user. The results suggest that the global revenues of streaming services may not be directly linked to the local economic performance of the sector, while competitive pressures between platforms may negatively affect their monetisation models. The study contributes to a better understanding of the economic implications of music digitization and its results may be useful for policy makers, platform managers and cultural economics practitioners.

Keywords: digitalization, music industry, economic impact

Introduction

In the last decade, research in the music industry has focused heavily on the impact of digitisation and the development of streaming platforms, which are changing the way music content is distributed, consumed and monetised. Many studies analyse how platforms such as Spotify, Apple Music and YouTube influence listening habits, market structure and the position of music creators. Research also focuses on changes in the business models of music companies and the shift of economic value from the sale of physical media to subscriptions to digital services. A number of papers point out that although overall music industry revenues are growing, the question of their equitable distribution remains problematic, with widening disparities between global platforms and local creators.

Despite the availability of a large amount of data on revenue and usage trends in the digital environment, it remains unclear exactly how these revenues affect broader economic indicators, in particular the gross value added generated by the music industry in specific countries. Research to date has largely focused on consumer behaviour, changes in distribution channels or technological innovation, but less attention has been paid to direct quantitative analysis of the links between the performance of streaming platforms and macroeconomic indicators. At the same time, the literature rarely examines how competitive dynamics between platforms affect the economic efficiency of their monetization models.

The aim of this study is therefore to quantitatively investigate the relationship between streaming platform revenues and gross value added of the music industry, as well as to analyse possible competitive effects between the main market players. The work is based on a hypothetico-deductive approach and uses a correlation analysis based on secondary data from 2016 to 2023. The results offer new insights into the economic consequences of digitalization and can contribute to a better understanding of the structural changes in the music ecosystem. The study is structured as follows: the introduction is followed by a literature review, a methodology section, the results of the analysis, a discussion and a conclusion.

1. Literature Review

The last decade has brought revolutionary changes in the music industry. Digitisation has penetrated deep into the structure of the music sector and has fundamentally changed not only the way we make and listen to music, but also how it generates economic value (Lang, 2021). Traditional paradigms of selling physical media have given way to new forms of distribution and monetization, and these changes have created entirely new value chains across the industry (Bloomberg, 2024).

The advent of platforms like Spotify, Apple Music and YouTube Music didn't simply change the medium - it represented a fundamental reorganisation of the entire music ecosystem. The latest figures confirm this dramatic shift: according to the IFPI, music industry revenues have doubled since 2014 to a whopping $29.6 billion, with streaming services accounting for a dominant 69% of total revenues. This transformation is particularly pronounced in the Slovak context (Antal, 2019).

The Slovak music market recorded a significant revenue growth of 18.6% in 2022, reaching a total value of EUR 21 million. Similar to global markets, Slovakia is dominated by streaming services, with up to 44% of revenue coming from subscription streaming services and a further 20% from ad-supported streaming. Interestingly, despite the digital boom, the physical media sales segment paradoxically saw a 3% increase, while vinyl record sales grew by up to 10%. This seemingly contradictory trend reflects a nostalgic return to analogue media in response to the ubiquitous digitalisation (SOZA, 2020).

1.1 Technological foundations of transformation

The digital transformation of the music industry does not stand on one innovation alone. It is a complex set of technological revolutions involving the digitisation of sound, the rise of the mobile internet, sophisticated audio file compression, peer-to-peer technologies, cloud computing, and, in the most recent era, algorithmic content selection and machine learning. These innovations are intertwining and reinforcing each other, creating a whole new framework for the music business to operate (Benga & Elhamma, 2024).

It is the algorast rhythmic curation of streaming services that represents one of the most significant shifts - it has dramatically changed the way listeners discover new music. Recommendation systems based on listeners' prior preferences have replaced traditional radio playlists and manually curated music collections. This shift fundamentally affects artists' chances of success and is directly related to the economic value they are able to generate (Andreescu, 2021).

1.2 Growth of the global streaming market

Global revenues from subscription-based streaming are growing at a staggering rate. It is expected to reach $95.3 billion in 2023, an 18% increase from the previous year. Analysts predict that by 2027, these revenues will grow by a further 73% to reach a staggering $137 billion. Behind this growth is a sharp increase in the number of subscribers - from 610 million in 2017 to more than 1.16 billion in 2022. In Slovakia, this trend is illustrated by the fact that 110,000 new users of streaming services will be added in 2022 alone, bringing the total number of users of paid streaming services to over 600,000 individuals or households in 2023. This market penetration brings major economic implications for the entire sector (Zive.sk, 2025).

1.3 The changes and challenges of the digital era

In addition to opportunities, digitalisation has brought significant structural changes and challenges. The concentration of the market around dominant global platforms has changed the balance of power in favour of the tech giants, raising questions about the sustainability and fairness of such an arrangement. The paradox of the streaming model is that, despite rising overall revenues, remuneration for the creators themselves remains problematic. The typical musician gets only a fraction of a cent per play from platforms like Spotify. This disproportion has sparked several controversial discussions about the sustainability of artistic creation in the digital environment. Several prominent artists have even removed their work from streaming services to protest the low remuneration (Statista, 2024).

The problem is compounded by the impact of global distribution. While American, Chinese and British artists benefit from large domestic markets (these three countries together account for up to 65%

of total streaming revenues), artists from smaller countries, including Slovakia, face an even tougher playing field. This creates a vicious circle where insufficient revenues limit opportunities to invest in the quality of recordings, further reducing competitiveness (Springer, 2021).

The speed of digital innovation is forcing all players in the music industry to constantly adapt. The "streaming wars" between giants such as Netflix, Apple, Amazon and others have led to unprecedented investment in content. Over the past five years, media companies have invested nearly $445 billion in video content in an effort to gain viewers. Similar competitive pressures exist in music streaming. In this environment, investments in data analytics and content personalisation are proving crucial. Successful streaming platforms use sophisticated algorithms to predict listener preferences, allowing them to optimise catalogues and maximise user engagement. However, these technological capabilities create a significant barrier to entry for new players, further reinforcing the dominance of incumbent platforms (Business Insider, 2023).

1.4 The future of the music industry in the digital era

The digital transformation of the music industry is an irreversible process that will continue for years to come. New technologies such as augmented reality, virtual reality and generative artificial intelligence are bringing about another wave of change, the economic implications of which we are only just beginning to understand. In response to the limitations of the streaming model, alternative approaches to monetising music are emerging. Direct fan support through platforms such as Patreon or Bandcamp, new forms of music licensing for commercial use, exclusive digital events or the sale of digital NFT assets are just some of the innovative approaches. These alternatives allow artists to create economic value outside traditional channels (Hesmondhalgh et al., 2021).

Another important trend is the synergy between digital music and live performances. Paradoxically, in an era of unlimited digital access to music, the value of unique live experiences has increased. Concerts, festivals, and tours are the primary source of revenue for many artists, while digital distribution is primarily used to build audiences (Santarius, 2023). Issues of sustainability of the music industry in the digital era require not only market solutions but also regulatory interventions. The European Union has adopted several legislative measures, including the Directive on Copyright in the Digital Single Market, which aims to strengthen the position of creators vis-à-vis digital platforms. These regulatory initiatives can fundamentally affect the distribution of economic value in the music ecosystem (Camlin & Lisboa, 2021).

2. Methodology

The aim of this thesis was to analyse the impact of digitisation and the rise of streaming platforms on gross value added in the music industry, while also examining the competitive dynamics between the most important players in the digital market - Spotify and Apple Music.

The first step was to define the main research question, which focused on finding out how digitisation affects the economic added value in the music industry. Based on this question, we began to formulate the aim of the thesis and set out the methodological approach that we then used to process the data. We then went on to collect relevant literature that provided the theoretical basis for our analysis.

The data used in the research came primarily from secondary sources (Statista database) and covered the years 2016 to 2023. The main method of evaluation was gross value added, which is a key economic indicator that measures the contribution of producers, sectors or regions to the economy. The following formula was used to calculate GVA:

- GVA = gross domestic product + subsidies - taxes

Quantitative statistical methods of correlation analysis were used to process the data and detect relationships between variables:

- Pearson's correlation coefficient was used to assess the linear relationship between the UK music industry's gross value added and Spotify's total revenue between 2016 and 2023. Before calculating the correlation itself, the normality of the distribution was checked using the Jarque-Bera test, and the skewness and skewness values were analysed.
- Spearman's correlation coefficient was used to assess the relationship between Apple Music sales and average sales per user on Spotify, as these data did not show a normal distribution and may have exhibited non-linear monotonic relationships.

Two research hypotheses were formulated:

- H1: There is a positive correlation between the gross value added (GVA) of the UK music industry and Spotify's revenue between 2016 and 2023.
- H1.0: There is no correlation between the UK music industry's GVA and Spotify's sales.
- H2: There is a negative correlation between Apple Music's revenue and Spotify's average revenue per user from 2016-2023.
- H2.0: There is no correlation between Apple Music sales and average sales per Spotify user.

Analyses were performed in Microsoft Excel, using built-in statistical functions and manual checking of calculations

3. Results

3.1 Correlation between UK gross value added and Spotify's revenues

Pearson's correlation coefficient was used to examine the relationship between UK gross value added and Spotify's sales, as the aim was to see if there was a direct linear relationship between the two variables.

Table 1. Correlation:UK Gross Value Added / Sportify Revenue

Year	Gross added United (£bn)	Revenu Spotify (€bn)
2016	4,50	2,94
2017	5,00	4,62
2018	5,80	5,52
2019	5,80	6,76
2020	3,17	7,88
2021	4,00	9,66
2022	6,70	11,72
2023	7,60	13,24
Skewness	0,1141	0,3076
Pointedness	-0,5783	-1,0631
Jarque-Bera test	0,1288	0,5029
Coef. correlations	0,5084	
P-value	0,1983	

Source: own processing according to UK Music report and Spotify data

The Pearson correlation coefficient is appropriate to use for data that have an approximately normal distribution - we verified this condition using the Jarque-Bera test. The test results (0.1288 for gross value added and 0.5029 for Spotify sales) showed no significant deviations from normality, and this is also true for the skewness values. While the skewness does indicate a slightly asymmetric distribution for Spotify sales, the value only marginally exceeds the established data normality interval of -1 to 1. Therefore, given these results and the normality of the other data, we chose Pearson's correlation coefficient.

The Pearson correlation coefficient value of 0.5084 indicates a moderately strong positive correlation between the variables analysed. This means that as GVA increases in the UK, Spotify's sales tend to increase, although this relationship is not entirely straightforward. However, an important aspect in interpreting the results is the p-value of 0.1983, which is higher than the commonly used statistical significance threshold of 0.05. This correlation is therefore not statistically significant and therefore it cannot be said with certainty that there is a direct relationship between UK economic performance and Spotify's sales.

The slight correlation may be due to the fact that although a country's economic growth may influence consumer behaviour, Spotify's sales are primarily influenced by global trends in digital consumption. For example, in 2020 and 2021, UK GVA declined due to the pandemic, while Spotify's sales continued to grow. This suggests that Spotify's success in the market is not closely tied to the evolution of one country's economy, but rather to factors such as subscriber growth, expansion into new markets and innovation in content monetisation.

3.2 Correlation between Apple Music sales and Spotify sales per user

The correlation between Apple Music revenue and Spotify's average revenue per user was calculated using Spearman's correlation coefficient. This indicator is appropriate in this case because it allows monotonic relationships between variables to be examined without the assumption of linearity.

Table 2. Correlation: Apple's revenue/ Spotify's revenue per user

Year	Apple Music revenue (€bn)	Order	Spotify user complaints (£bn)	Order
2016	1,58	8	6,20	1
2017	2,14	7	5,32	2
2018	3,26	6	4,89	3
2019	4,09	5	4,86	4
2020	5,86	4	4,41	5
2021	6,51	3	4,29	6
2022	7,72	2	4,54	7
2023	8,56	1	4,27	8
Skewness	0,0526		1,4373	
Pointedness	-1,5680		1,9821	
Jarque-Bera test	0,8232		4,0639	
Coef. correlations	-0,9286			
P-value	0,0009			

Source: Own processing based on Apple Music and Spotify data

The decision not to use Pearson's correlation coefficient was based on the results of the skewness analysis, the skewness and the Jarque-Bera test, which indicated that the data deviated from a normal distribution. Since the Pearson coefficient assumes a normal distribution and a linear relationship between the variables, its use would not be appropriate in this case. Conversely, Spearman's correlation coefficient, which works with the order of the values instead of their absolute numbers, is more appropriate for capturing the relationship between Apple Music revenue and average revenue per Spotify user.

The Spearman correlation coefficient reached -0.9286, which represents a very strong negative correlation between the two variables. This result implies that as Apple Music revenue increases, the average revenue per Spotify user decreases. The p-value of 0.0009 confirms the statistical significance of this correlation, which allows us to state with a high degree of confidence that the observed dependence is not random.

The strong negative correlation may be due to several factors. One is the increasing competitiveness of Apple Music, which may be putting pressure on Spotify, forcing it to offer lower subscription prices or expand free services, leading to a reduction in average revenue per user. In addition, this trend may also be affected by wider changes in the music industry.

In terms of business strategy, Spotify should consider adjusting its current monetization models, such as increasing premium subscription prices, targeting ads more in the free version, or expanding its premium content offerings. If the company were able to increase the added value that subscribers receive on paid services, which could also motivate free users to activate premium subscriptions, thereby mitigating the decline in average revenue per user while maintaining a competitive advantage in the market.

4. Discussion

The findings of this study show that digitisation through streaming platforms significantly affects the economic parameters of the music industry. Statistical analysis showed a moderately strong positive correlation (r = 0.5084) between the gross value added (GVA) of the UK music industry and Spotify's sales, but this relationship was not statistically significant (p = 0.1983). In contrast, a very strong negative correlation was found between Apple Music sales and Spotify's average sales per user (r = -0.9286, p = 0.0009), indicating a clear competitive pressure between the platforms.

4.1 Hypothesis-based analysis

- H1: There is a positive correlation between the UK music industry's GVA and Spotify's sales.
- H1.0: There is no correlation between these variables.

The results of the analysis for H1 showed a moderately strong positive correlation (r = 0.5084), which is consistent with the assumption that Spotify's revenue growth may be related to the rising economic performance of the music sector. However, given the p-value of 0.1983, this correlation was non-statistically significant and hence the null hypothesis H1.0 was not rejected. In other words, based on the available data, we cannot confirm that there is a significant relationship between the variables analyzed. One explanation for this is that Spotify's sales are global in nature, whereas HPH was only analysed for the UK. According to Andreescu (2021), GVA is generated in a regional context and the global revenues of digital platforms may not be directly reflected in local economic data. Similarly, Bloomberg (2024) highlights that Spotify is expanding mainly outside traditional markets and revenue growth may not follow the development of a specific national industry.

- H2: There is a negative correlation between Apple Music sales and average sales per Spotify user.
- H2.0: There is no correlation between these variables.

In this case, the H2 hypothesis was confirmed. The Spearman correlation coefficient reached -0.9286, with a p-value of 0.0009 confirming high statistical significance. This means that as Apple Music sales increase, Spotify's average sales per user decrease significantly. This trend can be explained by increasing competition, which forces Spotify to lower prices, introduce discounts or expand free services. Benga and Elhamma (2024) describe this phenomenon as "digital competitive pressure", where the dominance of multiple players leads to a weakening of individual returns. Similarly, Hesmondhalgh et al. (2021) point out that the monetization model of streaming is increasingly challenging for both creators and platforms, leading to declining revenue per user.

This study was limited by several factors that affected the interpretability of the results. First and foremost is the geographical limitation - while gross value added was only analysed for the UK music industry, the sales of streaming platforms such as Spotify and Apple Music are global in nature. This discrepancy in the scope of the data may have affected the correlations between variables. In addition, the analysis was only carried out on aggregated annual data from 2016 to 2023, which does not allow for seasonal or short-term fluctuations to be captured. Another important limitation is that while correlation methods detect the strength and direction of the relationship between variables, they do not allow causal relationships to be inferred. Control variables, such as the number of active users, advertising investment or licensing expenditure, which could shed more light on the relationships analysed, were not included in the research.

Based on the above, we recommend that future research should extend the analysis to other countries in the European Union to compare the differences between larger and smaller markets for digital music. It would also be advisable to apply multivariate regression analysis, which would allow for the identification of more complex relationships between multiple variables simultaneously. Supplementing the quantitative research with qualitative interviews with practitioners such as representatives of streaming platforms, music labels and artists themselves could also be of significant benefit. Last but not least, the impact of new forms of monetisation such as Patreon, NFT or crowdfunding models, which are gaining importance as alternatives to the traditional streaming model and have the potential to influence the creation of economic value in the music sector in the coming years, should also be explored.

5. Conclusion

The aim of this thesis was to analyse the impact of digitisation and the rise of streaming platforms on gross value added in the music industry, while also examining the competitive dynamics between the most important players in the digital market - Spotify and Apple Music. Based on the correlation analysis carried out, it can be concluded that although there is a positive correlation between Spotify's sales and the gross value added of the UK music industry, it was not statistically significant. On the contrary, the analysis showed a strong and statistically significant negative correlation between Apple Music's growing sales and Spotify's declining average sales per user, indicating intense competitive tensions between the two dominant platforms.

The main contribution of this thesis is that it provides a quantitatively grounded insight into how digital technologies and business models affect economic indicators in the music industry. In particular, the findings can be used in practice by managers of streaming platforms, music content creators or cultural management professionals. They point out that revenue growth of streaming platforms alone may not automatically translate into an increase in economic value for the whole sector, especially if profits are concentrated in a narrow segment of multinationals.

At the same time, the thesis highlights the need to diversify revenue models for music creators and the importance of regulation in the digital environment, especially in the area of fair remuneration. Thus, the results of this study open up space for further research on the sustainability of the digital music market as well as on a fairer and more inclusive structure.

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Strategic management of the transition to circular models: Analysis and comparison of approaches in European Countries

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Abstract: The circular economy is currently recognized as a fundamental concept for achieving sustainable development, especially considering the continuously increasing volume of generated waste and the mounting pressure on limited natural resources. This paper analyzes the strategic management of transitions towards circular models within the European Union member states, a crucial element for the effective transformation of economic systems. The research was conducted using cluster analysis, enabling the identification and examination of differences in the capabilities of individual EU member states to strategically manage the transition to circular economic models. Data collection was carried out through the Eurostat database, selecting key indicators relevant to the circular economy. The findings identified three primary segments of countries based on their capabilities to implement and manage circular principles, highlighting diversity in progress and effectiveness among the member states.

Keywords: Circular economy, circular business models, European Union

Introduction

Recently, the circular economy has emerged as a pivotal concept in discussions surrounding sustainable development and strategic management. Given the growing challenges associated with efficient utilization of natural resources and the increasing volumes of generated waste, the search for new approaches and innovative solutions has become essential. The circular economy represents a revolutionary model that not only reduces waste production but also fosters recycling and reuse of resources, thus paving the way towards an environmentally sustainable and economically advanced future. Within the context of the analyzed European Union countries, appropriately established legislation, programs, plans, and frameworks play a crucial role in their transition toward circular economy principles. This paper builds upon theoretical insights regarding the circular economy and its fundamental nature, as well as international strategies and initiatives that regulate and promote the adoption of the circular economy and sustainable development in the EU. The aim of the paper's research is to identify and analyze differences among EU member states in their capacities to strategically manage the transition to circular economic models. Specifically, the paper investigates how various EU countries have implemented strategies supporting the circular economy, utilizing selected indicators analyzed through cluster analysis. Consequently, the findings contribute to a deeper understanding of the current state of the circular economy in the observed countries and the effectiveness of implementing its core principles.

1. Literature Review

The chapter outlines the fundamental nature and significance of the circular economy, describing key EU strategies and initiatives that support the transition of member states towards circular economy principles.

1.1 Fundamental principles and significance of the circular economy

The concept of the circular economy (CE) originates from Ayres' (1994) work on industrial ecology, which introduced a model inspired by natural cycles. This approach gained popularity in the early 21st century, responding to the increasing need to replace the traditional linear production-consumption system with one minimizing waste and maximizing resource efficiency (Geissdoerfer et al., 2017; Kirchherr et al., 2017). CE represents a sustainable model emphasizing the principles of reduce, reuse, and recycle (3R), aimed at minimizing waste and optimizing resource use. Numerous authors agree that achieving a CE model involves strategies such as extending product lifespan by closing, slowing, and narrowing material flows, and transforming waste into valuable resources. These strategies enable improved resource regeneration and reduction of environmental impacts. Different EU countries have adopted varied approaches to resource management, waste reduction, and enhancing energy efficiency, thus supporting responsible consumption aligned with sustainable development goals (Ellen MacArthur Foundation, 2015; Geissdoerfer et al., 2017; European Commission, 2020; Jurkovič, 2020). Kirchherr et al. (2017) highlight that CE diverges significantly from the conventional linear lifecycle of products, emphasizing reduction, reuse, recycling, and recovery of materials at every production, distribution, and consumption stage. Geng et al. (2012) support this assertion, noting that such an approach not only addresses environmental concerns but also enhances economic sustainability and social equity at micro, meso, and macro levels.

According to Assmann et al. (2023), CE offers substantial environmental benefits, including emissions reduction and more efficient resource use, thereby harmonizing economic growth with environmental protection. Smol et al. (2020) stress that reusing materials is crucial for waste reduction and process sustainability. Furthermore, a study by Circle Economy & Ecofys (2016) revealed that the implementation of circular business models (CBMs) enhances the robustness of supply chains, reduces production costs, and promotes sustainability across various countries and industries. Despite these theoretical benefits, the adoption of CE faces several obstacles in businesses and public institutions. Assmann et al. (2023) identified eight primary factors influencing the adoption of CBMs, including cultural, regulatory, and market factors, strategic approaches, business opportunities, collaboration, operational processes, and professional competencies. These factors suggest that successful CE implementation requires technological innovations as well as shifts in organizational culture, legislation, and consumer habits. In this context, governmental policies play a moderating role in implementing CBMs by increasing the perceived legitimacy and availability of circular products. Effective national regulations and strategies can facilitate smoother transitions toward circular practices, as indicated by Kumar et al. (2024) and Chen et al. (2024). These findings underscore the significance of governmental support in enhancing the effectiveness and acceptance of circular initiatives within economic and regulatory frameworks.

Mahpour (2018) highlights major barriers to CE implementation, such as inadequate legislative support, weak integration of sustainable practices, and a preference for cheaper yet unsustainable solutions. Assmann et al. (2023) emphasize that an efficient circular economy enables companies to adopt CBMs, leading to reduced costs and enhanced resilience in supply chains. This approach also includes establishing markets for recycled materials and implementing environmentally focused taxes and regulations.

Integrating circular economy principles into strategic management within organizations and the public sector represents a critical step towards long-term sustainability, surpassing traditional objectives such as resource efficiency and waste reduction. According to Klein et al. (2020), effective implementation of these principles requires strong leadership, clear alignment of these objectives within organizational missions, and robust strategic plans supporting these values at all management levels. Concurrently, Chareonvong et al. (2025) highlight that strategic management in adopting circular models necessitates deep integration of these principles into municipal waste management systems, addressing challenges related to funding and infrastructure. Furthermore, supporting educational initiatives enhances community awareness and involvement, not only reducing waste and conserving resources but also creating opportunities for green employment through efficient recycling and material reuse.

1.2 Key strategies and initiatives

The European Union has long supported the development of the circular economy (CE), emphasizing the more efficient use of resources. A pivotal milestone in this area was the European Commission's Thematic Strategy on the Sustainable Use of Natural Resources from 2005, which laid the foundation for current EU circular economy policies. This strategy highlighted the importance of resource efficiency, aiming to decouple economic growth from resource consumption to minimize environmental impacts and optimize natural resource utilization (European Economic and Social Committee, 2019). Subsequently, the European Commission's Roadmap to a Resource-Efficient Europe in 2011 further embedded circular economy principles into EU policymaking, calling for a transition toward an economy that conserves resources while being sustainable and resilient (European Commission, 2011).

A significant advancement, marking CE as a core element of the EU's economic strategy, was the introduction of the essential policy document titled "Closing the Loop – EU Action Plan for the Circular Economy 2015-2019" (European Commission, 2015). The Action Plan outlined a series of measures and proposals targeting optimization of product lifecycles and modernization of waste legislation, thereby strengthening markets for secondary raw materials. In 2018, the European Commission published the Circular Economy Monitoring Framework, which includes a set of key indicators designed to track the progress and effectiveness of circular economy measures implemented by EU member states (European Commission, 2018). This framework provides tools to assess the success of circular strategies and identify areas requiring further improvement or intervention. However, as noted by Mazur-Wiebriczka (2021), some EU countries developed "their own indicator systems," complicating the comparative assessment of circular economy initiatives across member states. Examples include the Netherlands, France, the French Ministry for Ecological and Inclusive Transition, Italy, and Portugal.

The subsequent Circular Economy Package (2018) consolidated these efforts through instruments designed to monitor progress, strategies aimed at reducing plastic waste, and harmonizing waste and product policies. These initiatives became an integral component of the European Green Deal by 2019, underscoring the importance of involving cities and regions in transitioning towards circular models (European Commission, 2020). The European Commission actively encourages EU member states to develop national strategies supporting the circular economy. As part of the updated Action Plan in 2020, the European Commission calls on member states to adopt specific measures and strategies facilitating the transition toward a circular economy (European Commission, 2020).

2. Methodology

The primary objective of this paper is to identify and analyze differences among European countries regarding their capabilities to strategically manage the transition to circular economy models. By applying quantitative analytical methods, countries are classified into homogeneous groups (clusters) based on key indicators associated with the implementation of circular economy principles. These indicators include the municipal waste recycling rate, the level of private investment in circular solutions, the circular material usage rate, employment in circular economy sectors, and gross value added related to circular economy activities. This classification aims to provide a data-driven perspective on existing differences among countries, identifying the strengths and weaknesses of individual segments, thereby enabling the formulation of recommendations for more effective implementation of sustainable development policies.

2.1 Data source and selection

The data used in this analysis were obtained from Eurostat's open-access database, with the selection of indicators guided by their relevance to the circular economy and their availability across European countries. Given that not all countries had complete data for the same periods, data from the years 2021–2023 were utilized to maintain the highest possible representativeness of the sample. The sample selection included EU member states for which sufficiently up-to-date data were available, resulting in a final sample of n = 27 countries. This selection enables meaningful comparisons between countries within the same political and economic framework and allows for a clearer interpretation of differences in the implementation of circular strategies. Table 1 presents the baseline dataset for the analysis.

Table 1. Values of selected CE indicators for EU member states

Unit	**Percentage**	**Percentage of gross domestic product (GDP)**	**Percentage**	**Percentage of total employment - numerator in full-time equivalent**	**Percentage of gross domestic product (GDP)**
Indicator	**Circular material use rate (2023)**	**Private investments value related to circular economy sectors (2021)**	**Recycling rate of municipal waste (2022)**	**Persons employed in circular economy sectors (2023)**	**Gross added value related to circular economy sectors (2021)**
Belgium	19.7	1.4	54.7	1.2	1.7
Bulgaria	4.9	0.6	24.6	2.7	1.5
Czechia	12.8	0.4	43.3	2.6	1.4
Denmark	9.1	0.9	45.7	1.3	1.8
Germany	13.9	0.9	69.2	1.7	2.2
Estonia	18.1	0.7	33.2	7.9	1.9
Ireland	2.3	0.6	40.8	1.3	2.9
Greece	5.2	0.1	17.3	1.5	0.5
Spain	8.5	0.5	42.9	2	1.9
France	17.6	0.8	41.2	1.8	1.6
Croatia	6.2	0.7	34.2	3.9	2.2
Italy	20.8	0.7	53.3	2	2.5
Cyprus	5.4	0.2	14.8	2.8	1.6
Latvia	5	0.7	50.8	3.6	1.5
Lithuania	3.9	0.8	48.4	4.2	1.8
Luxembourg	10.2	1	55.6	4.2	1.1
Hungary	5.9	0.7	32.8	2.3	1.7
Malta	19.8	1.1	12.5	2.7	2.9
Netherlands	30.6	1	57.6	1.1	1
Austria	14.3	1.4	62.6	1.4	2
Poland	7.5	0.7	40.9	2.3	1.8
Portugal	2.8	0.8	30.2	2.3	1.5
Romania	1.3	0.5	12.3	2.3	1
Slovenia	8.8	0.2	62.6	2.7	1.5
Slovakia	10.6	0.5	49.5	2.7	1.2
Finland	2.4	0.3	43.7	1.5	1.4
Sweden	9.9	0.4	39.7	1.5	1.4

Source: own processing based on statistical data from the Eurostat database (2025)

2.2 Methodological Approach

To classify countries into homogeneous groups, the analysis employed cluster analysis, following a multi-step analytical procedure. Given the differing scales of the selected indicators, all data were normalized prior to processing to ensure comparability and to avoid distortions caused by varying value ranges. Subsequently, the K-means clustering method was applied to identify the optimal number of clusters, with results evaluated using the Elbow Method. These metrics indicated that segmenting the countries into three groups was optimal. Once the number of clusters was determined, hierarchical cluster analysis – specifically Ward's method – was used for the final classification. This method minimizes within-cluster variability while maximizing between-cluster differences and also allows for visualization of the results using a dendrogram.

For enhanced visualization and better interpretability of the clusters, a Principal Component Analysis (PCA) was conducted, enabling graphical representation of the segments in a reduced dimensional space. This approach helped identify the main factors influencing the assignment of countries to specific segments, providing additional insight into the observed differences. Calculations and analyses were performed using MS Excel, utilizing available tools for cluster analysis and PCA.

3. Results

The results of the cluster analysis revealed three distinct segments of countries, differing in their capabilities to strategically manage the transition to circular economy solutions. This segmentation was established using the Elbow Method, which identified three clusters as the optimal number for effective sample division. Each of these segments represents a group of countries with similar characteristics in their approach to implementing circular economy principles.

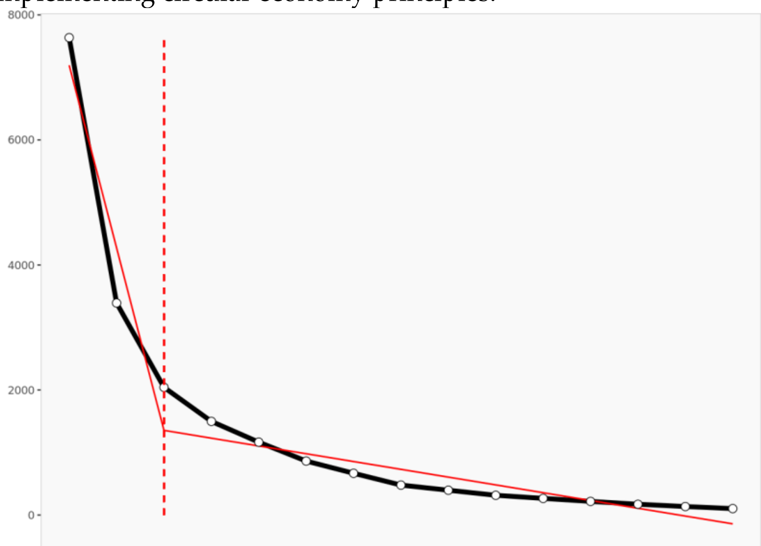

Figure 1. Visualization of the Elbow method for determining the optimal number of clusters

Source: own processing

Statistically significant differences were observed among the identified country segments in certain indicators, such as the circular material use rate, the level of private investment in circular solutions, and the municipal waste recycling rate. Detailed analytical information is provided in the following tables (Table 2, Table 3)

Table 2. Values of selected CE indicators for EU member states

Segment size	Sample	Segment 1	Segment 2	Segment 3
Absolute size	27	8	13	6
Relative size	100%	30%	48%	22%

Source: own processing

Table 3. Values of selected CE indicators for EU member states

Indicator	Population	Segment 1	Segment 2	Segment 3
Circular material use rate (2023)	10.28	6.44	9.07	18.02
Private investments value related to circular economy sectors (2021)	0.689	0.588	0.638	0.933
Recycling rate of municipal waste (2022)	41.3	22.3	44.3	60.0
Persons employed in circular economy sectors (2023)	2.50	2.56	2.84	1.68
Gross added value related to circular economy sectors (2021)	1.69	1.61	1.67	1.82

Source: own processing

In the context of analyzing the statistical significance of differences in individual indicators across segments, a graphical visualization has been prepared (Figure 2):

Figure 2. Visualization of statistical differences in selected CE indicators across segments

Source: own processing

The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted. The first segment comprises a group of countries labeled as “Emerging Circular Transition Countries,” including Greece, Bulgaria, Croatia, Cyprus, Hungary, Malta, Portugal, and Romania. These countries are in the early stages of implementing circular strategies and show relatively lower values in key indicators, particularly in recycling rates and investments in circular solutions. Their economies have historically relied more on linear production and consumption models, and the implementation of circular strategies is progressing more slowly.

The second segment, referred to as “Moderate Circular Leaders,” consists of Spain, France, Czechia, Denmark, Estonia, Ireland, Latvia, Lithuania, Luxembourg, Poland, Slovakia, Finland, and Sweden. These countries display moderately higher levels of circular economy adoption, with recycling and investment indicators suggesting a mid-range adaptation to circular economy principles. Countries in this segment have a more developed regulatory framework and higher investments in sustainable solutions, though there remains room for improvement, particularly in optimizing secondary material flows and fostering innovation.

The third segment, "Advanced Circular Champions," includes Belgium, Germany, Italy, the Netherlands, Austria, and Slovenia. These countries are leaders in the circular economy, achieving the highest scores in key indicators, excelling in recycling processes, investments in innovative solutions, and efficient material flow management. They also benefit from strong political support for circular solutions and a high level of collaboration between research institutions and industry.

The analysis highlights significant differences between the segments across key variables, with the statistical significance of some underscoring the diversity of country capabilities in the circular economy domain. Segment 3 demonstrates the highest circular material use rate, averaging 18.02%, reflecting its ability to efficiently process material flows. By contrast, Segment 2 averages 9.07% and Segment 1 6.44%, indicating lower recycling efficiency and greater reliance on primary resources. Regarding private investments in the circular economy, Segment 3 stands out with an average of 0.93% of GDP, signaling successful integration of circular economy practices into business models. Meanwhile, Segment 2, with investments of 0.64% of GDP, and Segment 1, with 0.59% of GDP, point to a need for stronger incentives, hindered by factors such as insufficient regulatory conditions or limited access to financing.

A similar trend is observed in the municipal waste recycling rate, where Segment 3 excels at 60%, reflecting high efficiency in waste processing. Segment 2, at 44.28%, demonstrates a well-developed infrastructure but still leaves room for further improvement. Segment 1, at 22.34%, indicates weaker development of recycling infrastructure, collection, and processing systems, along with lower levels of implementation of relevant laws and legislative measures.

The following figures (Figure 3, Figure 4) provide visualizations of the presented findings to enhance understanding of the cluster analysis. The dendrogram (Figure 3), based on the Elbow Method, illustrates the optimal number of segments and the detailed distribution of countries.

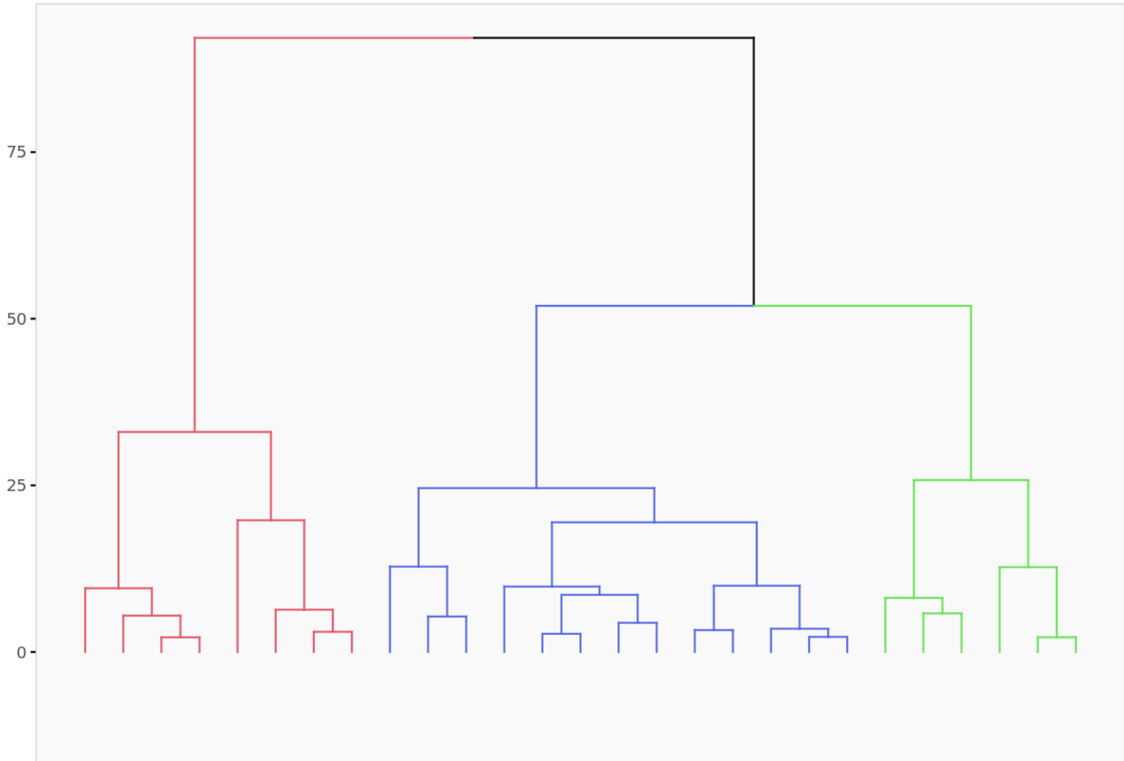

Figure 3. Dendogram of the Cluster analysis

Source: own processing

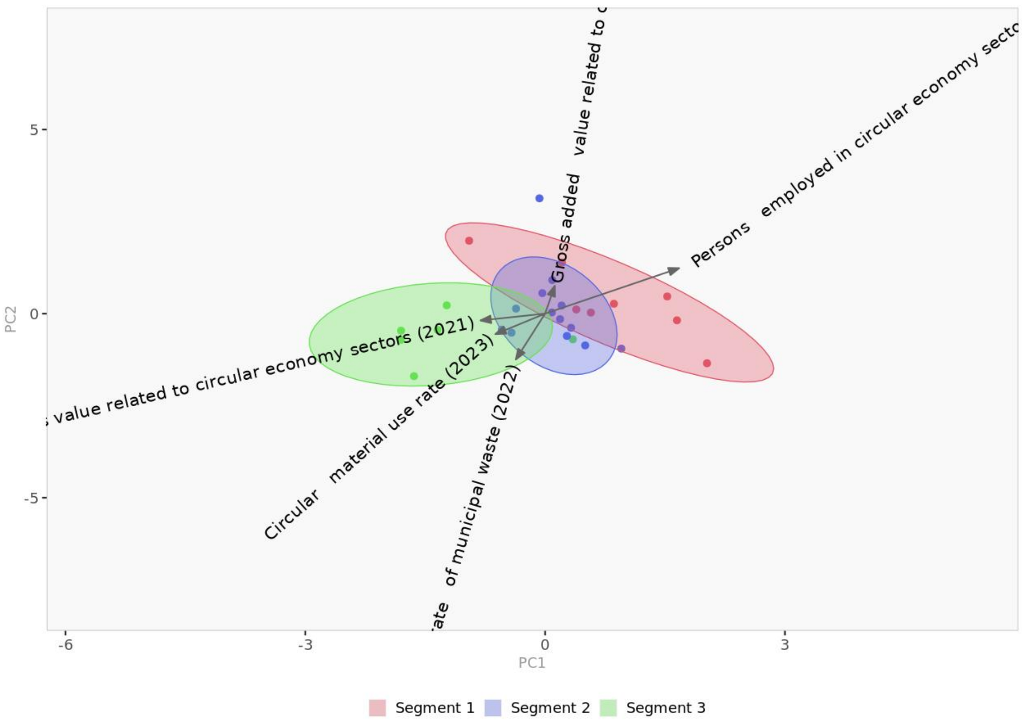

Figure 4. Distribution of countries by key indicators

Source: own processing

Figure 3 illustrates the results of the PCA analysis, where individual points represent specific data for each of the analyzed indicators. The colors (green, blue, red) correspond to different segments or groups of countries identified as homogeneous clusters based on their performance in the given indicators. The PC1 and PC2 axes (First and Second Principal Components) display the two dimensions in which the data exhibit the greatest variability. The elliptical areas surrounding the segments indicate the data dispersion within each cluster, showing how concentrated or dispersed the data are within the clusters.

4. Discussion

Based on the presented results, it is evident that the transition to circular solutions is not a homogeneous process but is influenced by national policies, investment levels, and regulatory frameworks. The findings of this paper's analysis confirm previous studies on the clustering of EU countries in their transition to circular models. As noted by Mazur-Wierzbicka (2021), countries such as Germany, Belgium, Italy, and the Netherlands are regarded as leaders and are the most advanced in applying circular economy principles. The experiences of countries in Segment 3 can thus serve as valuable benchmarks for developing benchmarking studies and policy recommendations for countries in other segments. These countries should continue investing in highly efficient models for closing material loops and in the implementation of advanced digital solutions for waste flow management. They benefit from strong national strategies and initiatives such as Germany's National Circular Economy Strategy, Flanders Circular, the Circular Economy Network, and the Netherlands Circular Hotspot, among others (European Environment Agency, 2024).

Countries in Segment 2, including Spain, France, Czechia, Denmark, Estonia, Poland, Slovakia, and others, demonstrate positive progress in implementing circular economy strategies but face the challenge of strengthening the link between developed policies and their practical application. Key measures for this segment should include targeted investment incentives and increased support for private investments in circular economy projects. These countries should also focus intensively on developing public-private partnerships and establishing innovation hubs, contributing to the dynamic development of circular solutions.

Segment 1, which includes countries such as Romania, Bulgaria, Hungary, and Greece, faces significant challenges in the circular economy domain. For these countries, it is critical that governments formulate and implement regulatory environments that stimulate circular innovations and provide robust support for entrepreneurs in this field. This should include the introduction of state incentives and tax reliefs for activities focused on the circular economy. Additionally, a priority for these countries is the development of efficient waste management systems through strategies aimed at reducing landfilling, creating effective collection and separation systems, and increasing recycling rates. Such approaches and strategies could significantly contribute to a faster and more efficient transition to sustainable economic models within the European Union, as emphasized by Nowak-Marchewka et al. (2025) in their study.

5. Conclusion

In conclusion, this paper confirms that the transition to circular economy models is a complex and differentiated process, influenced by a wide range of factors, including national policies, investment support, and regulatory frameworks. The analyses conducted, encompassing cluster analysis and comparisons of selected indicators, enabled the identification of differences in the capacities of individual EU member states to strategically manage the transition to circular economic models.

The first step involved forming homogeneous groups (clusters) of countries based on key indicators related to the implementation of circular economy principles, such as the municipal waste recycling rate, the level of private investment in circular solutions, the circular material use rate, employment in CE sectors, and the gross value added associated with CE sectors. The cluster analysis revealed three distinct country segments, differing in their capabilities and approaches to implementing circular principles.

The results of the analysis indicate that some countries are more advanced in their transition to a circular economy, while others still face significant challenges. These differences are statistically significant and highlight the need for targeted support and strategic interventions to overcome existing barriers and enhance the effectiveness of the transition to more sustainable economic models.

This paper contributes to a deeper understanding of the strategic management of EU countries' transition to circular models by analyzing key indicators supporting circular principles. The findings provide valuable insights for policymakers and stakeholders, underscoring the need for tailored strategies to support sustainable practices at the national level. Future research should include more detailed analyses of sector-specific data, multifactor analyses, and investigations into the long-term impacts of individual strategies.

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The impact of the gender structure of employment in the cultural industries on the level of household expenditure on recreational and cultural services in European countries over the last period

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Abstract: This paper examines the impact of the gender structure of cultural industry employment on the economic performance of the sector, with a particular focus on the level of household spending on recreational and cultural services in European countries (2015-2022). The aim of the research is to analyze the relevance of gender diversity as a sectoral factor for the development of predictive models of economic performance and enterprise value in the cultural and creative industries. The use of quantitative methods, including panel regression analysis and analysis of variance (ANOVA), allows for the examination of regional differences and temporal trends in variables, thus contributing to methodological inputs for dynamic valuation models. The paper provides a deeper insight into the issue of gender equality and its potential economic impacts within the cultural and creative industries in Europe. The results of the analysis provide new insights that contribute to the debate on the relevance of the gender structure of employment in the context of households' economic and consumption behavior.

Keywords: gender structure of employment; cultural industries; household spending

Introduction

Cultural and creative industries play a crucial role in today's European economies and contribute significantly to economic growth, employment, innovation and social cohesion (KEA, 2019). Within these industries, gender diversity and employment patterns are increasingly coming under scrutiny as gender equality is considered an important topic in the economic sustainability and inclusive growth of societies (European Institute for Gender Equality, 2021). Understanding the relationship between gender composition in cultural employment and household spending on recreation and cultural services reflects broader societal shifts towards gender-balanced participation.

Recent socio-economic trends, such as the digital transformation precipitated by the COVID-19 pandemic, have altered cultural consumption and employment, thereby affecting gender representation and consumption behavior in cultural contexts (OECD, 2022). At the same time, policies at both European and national levels have focused on promoting gender equality, not only from a human rights perspective, but also as a pragmatic strategy to enhance economic performance and consumer markets (European Commission, 2020).

Despite extensive research that specifically focuses on gender equality in employment and cultural consumption patterns, there remains a significant gap regarding their interrelationship. Previous studies have documented the impact of gender diversity on workplace productivity and innovation across industries, but limited attention has been paid specifically to the cultural and creative industries and their link to household consumption expenditures (Banks, 2017; Oakley & Ward, 2018). In addition, there are relatively few comparative studies examining different European countries, presenting an opportunity for more in-depth research.

1. Literature Review

Analysis of gender structures in the cultural and creative industries has expanded significantly internationally, shedding light on persistent disparities and potential economic and social impacts. Extensive research by the European Institute for Gender Equality (EIGE, 2021) highlights that despite making up a significant proportion of the cultural workforce, women are still underrepresented in senior and high-value creative roles (UNESCO, 2025). In this context, there is a need for a systematic analysis to incorporate these factors into comprehensive predictive models for assessing businesses and their economic potential.

Oakley and O'Connor (2015) highlight that gender inequalities in creative industries directly shape cultural products, consumer engagement and market dynamics. Their research identifies the significant impact of gender-balanced creative teams on the diversity of cultural offerings, potentially stimulating greater household engagement and higher spending on cultural activities. Similarly, UNESCO's research (2025) highlights the economic benefits associated with gender equality in the cultural industries, linking increased gender equality to increased rates of innovation, market expansion and increased consumer spending patterns.

At the national level, the countries of Central and Eastern Europe, including Slovakia, present a specific cultural employment context characterized by slower progress on gender equality compared to Western Europe. According to Slovak government reports (Ministry of Culture of the Slovak Republic, 2021), structural inequalities in cultural employment remain entrenched, characterized by the limited representation of women in senior creative and leadership positions. These reports further suggest that persistent gender inequalities in the sector could constrain overall market development, innovation and cultural diversity, which in turn would affect consumption patterns and domestic market growth.

International comparative studies provide crucial insights into how different national policies and gender norms affect economic outcomes in cultural sectors. OECD (2022) identified significant correlations between gender-balanced employment policies and increased resilience and market dynamism in cultural industries during recent global crises such as the COVID-19 pandemic. However, despite these valuable insights, explicit comparative research directly linking gendered patterns of cultural industry employment and household spending on culture in different European contexts is still limited. Banks (2017) notes that while there is a conceptual understanding of the potential economic impact of gender equality in the creative industries, the empirical evidence remains fragmented and insufficiently comparable. There is therefore an urgent need for systematic analyses that explore these interrelationships in depth and in different European socio-economic contexts.

Gender diversity has become a key indicator and a topic of intense professional debate in the international cultural and creative industries. According to a study by Hesmondhalgh and Baker (2015), the representation of women in the creative industries remains uneven, with women often concentrated in lower paid, lower status positions such as administrative or organizational roles, while creative and leadership positions are still predominantly occupied by men. These inequalities are not only reflected in career opportunities but also have economic implications that affect household spending patterns.

Foreign studies in the UK and Germany, for example, highlight that higher representation of women in decision-making positions in the cultural industries leads to a greater diversity of cultural production, thus directly supporting a broader consumer base (Conor, Gill & Taylor, 2015). This gender diversity in the management and production of cultural content directly correlates with greater consumer interest, which is particularly evident in higher household spending on recreational and cultural activities.

In the Scandinavian countries, which traditionally rank at the forefront of gender equality, the positive impact of gender diversity is clearly reflected in economic performance. Using Sweden as an example, Larsen E., et al. (2021) show that active government policies to promote gender equality in the cultural industry have contributed significantly to higher household interest in cultural events and services. In contrast, countries with less developed gender equality policies in the cultural sector, such as those in South-Eastern Europe (e.g. Romania, Bulgaria), show lower levels of cultural consumption and slower economic growth in this sector. These countries also face deeper societal barriers that prevent women from accessing leadership positions, limiting their potential for significant economic and social gains (Petrović, 2020).

2. Methodology

In this section, we focus on research objectives, hypotheses and methodological approaches to investigate the impact of the gender composition of employment in the cultural industries on household expenditure on cultural and recreational services in European countries. The clearly defined methodology provides a solid foundation for the analysis and interpretation of the empirical findings that are examined in this paper.

The main objective of this paper is to examine the impact of gender composition in the cultural industries on household spending on cultural and recreational services in European countries between 2015 and 2022. The aim of this investigation is to shed light on how women's representation in this sector may shape consumption behavior and spending patterns in the context of broader socio-economic dynamics. As a result, we aim to confirm or refute the hypothesis that a higher share of women's employment in the cultural industries has a directly proportional effect on household spending on cultural and recreational services. This hypothesis is based on the idea that the gender composition of the cultural workforce may influence market trends and consumer preferences and thus contribute to changes in expenditure patterns.

The paper focuses on two variables and their evolution over time: the gender composition of employment in the cultural industries, specifically the percentage of women employed in the cultural industries, and household expenditure on cultural and recreational services over the period under study. The data used in this study come from Eurostat and include panel data for the period 2015 to 2022, allowing for a reliable analysis of trends and regional differences relevant for the construction of a dynamic predictive model. Based on their initial selection due to the completeness of the data for the period under study, we have divided the European countries as follows: among the Northern European countries, we have included Denmark, Estonia, Finland, Iceland, Ireland, Latvia, Lithuania and Sweden. Belgium, France, Luxembourg, the Netherlands, Germany and Austria were classified as Western European countries. For Southern Europe we have included Croatia, Cyprus, Greece, Italy, Malta, Portugal, Spain, Slovenia and Serbia. In the last, Eastern Europe, we included Bulgaria, Czech Republic, Hungary, Poland, Romania and Slovakia. (UNSD, 2025)

The time span of the data provides a reliable basis for observing trends and changes over time, especially in the context of a dynamic economic environment and evolving cultural policies. To implement the research framework, the variables are identified as follows: the dependent variable is household expenditure on cultural and recreational services, which is captured both in absolute monetary terms and as a percentage of gross domestic product (GDP). The independent variable is the percentage of women employed in the cultural industries. This variable is crucial for assessing the expected impact of gender composition on cultural consumption.

We define the research hypotheses as follows:

H0: There is no statistically significant effect between the evolution of the percentage of women employed in the cultural industries and household expenditure on cultural and recreational services.

H1: There is a statistically significant effect between the evolution of the percentage of women employed in the cultural industries and household expenditure on cultural and recreational services.

The paper employs a quantitative research design using panel data analysis to capture both time trends and regional differences in the relationship between gender composition in cultural employment and household spending on cultural and recreational services in European countries between 2015 and 2022. The methodological approach is built on descriptive statistics and comparative statistics which ensures both breadth and depth of investigation of the proposed research problem. The overall design of the study follows a structured approach. At the outset, descriptive statistics are used to provide an overview of trends in gender composition and household expenditure in different European regions. These preliminary findings are followed by statistical tests to determine whether there are significant differences between the regions studied. For this purpose, an analysis of variance (ANOVA) is performed to test for mean differences between regional groups, using Welch's ANOVA in cases where homogeneity of variance is not met. In addition, post hoc comparisons using the Games-Howell test allow a more detailed assessment of which regional differences are statistically significant.

In addition to comparative statistical analyses, this study uses econometric modelling to examine the relationship between female employment in the cultural sector and household expenditure on cultural and recreational services. The basic methodological tool is linear regression analysis. The regression model is further tested using diagnostic procedures to ensure robustness and validity. The Shapiro-Wilk test is used to test normality, while the Levene test examines the homogeneity of variance across regions. In addition, the Durbin-Watson test is performed to check for autocorrelation of the residuals, thus ensuring the reliability of the estimated parameters.

3. Results

In this section, we will go through a comprehensive statistical analysis of data on the share of women employed in the cultural industries and the level of household spending on recreational and cultural services across different regions of Europe.

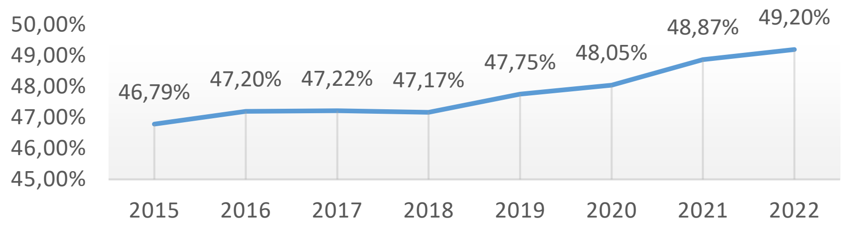
Table 1. Evolution of the percentage of women employed in the cultural industries over the reference period (2015-2022)

Region	2015	2016	2017	2018	2019	2020	2021	2022
Northern Europe	55.65%	55.28%	54.90%	55.44%	55.48%	54.34%	53.59%	54.81%
Western Europe	46.00%	47.38%	46.76%	47.36%	47.90%	48.07%	49.61%	49.89%
Southern Europe	44.30%	44.63%	45.10%	45.53%	46.36%	47.13%	46.32%	48.78%
Eastern Europe	50.86%	51.11%	51.51%	51.25%	50.94%	51.27%	52.47%	51.83%

Source: Author's own elaboration based on Eurostat data

Table 1 shows the evolution of the share of women employed in the cultural industries in the four European regions between 2015 and 2022. Northern Europe has the highest share over the long term, consistently above 54%, with minimal fluctuations. Western Europe has seen a gradual increase from 46% (2015) to almost 50% (2022), showing a steady positive trend. Southern Europe, which had the lowest share at the beginning (44.3%), gradually grew and approached 49% towards the end of the period. Eastern Europe remained relatively stable at around 51%, with slight variations, including an increase to 52.47% in 2021 and a subsequent decrease to 51.83% in 2022.

Figure 1. Evolution of the percentage of women employed in the cultural industries in the countries of the European Union over the reference period (2015-2022)



Source: Author's own elaboration based on Eurostat data

Figure 1 shows the share of women employed in the cultural industries in EU countries between 2015 and 2022. The data shows a steady increase from 46.8% (2015) to 49.2% (2022), despite slight decreases in 2018 (47.17%) and 2020 (47.75%). The most significant increase occurred between 2020 and 2021, which may be related to increasing job opportunities or changes in the structure of the workforce. The overall trend is towards a more balanced representation of men and women, probably due to policy measures and changing attitudes towards gender equality in the cultural sector.

Table 2. Evolution of the total number of employees in the cultural industries in thousands over the reference period (2015 - 2022)

Region	2015	2016	2017	2018	2019	2020	2021	2022
Northern Europe	86.08	87.46	86.28	86.68	89.06	87.49	86.40	92.18
Western Europe	538.95	547.62	561.70	569.55	578.75	558.90	594.45	629.70
Southern Europe	206.42	208.78	221.64	224.08	229.59	219.43	226.73	235.08
Eastern Europe	190.65	198.52	203.20	205.13	205.00	204.32	203.38	205.73

Source: Author's own elaboration based on Eurostat data

Table 2 shows the number of employees in the cultural industries (in thousands) in each European region between 2015 and 2022. Western Europe maintains the highest employment, growing from

539,000 (2015) to almost 630,000 (2022), reflecting strong demand and institutional support. Southern Europe shows similar growth from 206k to 235k, despite a slight decline in 2020. Eastern Europe sees moderate but steady growth in the range of 190-205k employees. Northern Europe, although with the lowest values (86 - 92 thousand), shows a steady increase, especially between 2021 and 2022.

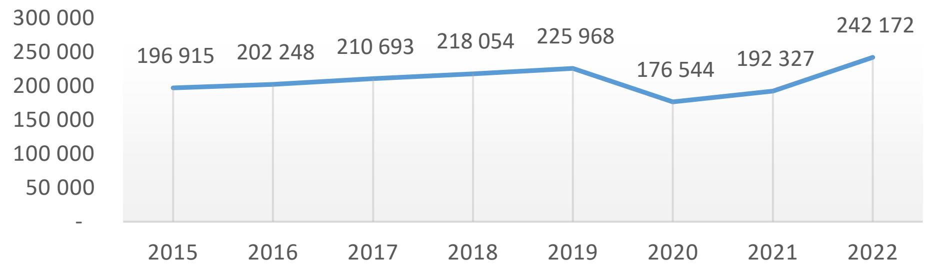
Table 3. Evolution of the level of household spending on recreational and cultural services as a percentage of GDP over the reference period (2015-2022)

Region	2015	2016	2017	2018	2019	2020	2021	2022
Northern Europe	1.78%	1.90%	1.94%	1.96%	2.01%	1.56%	1.60%	1.88%
Western Europe	1.42%	1.40%	1.43%	1.43%	1.48%	1.12%	1.07%	1.32%
Southern Europe	2.03%	2.02%	2.03%	2.08%	2.13%	1.60%	1.80%	2.09%
Eastern Europe	1.65%	1.73%	1.78%	1.72%	1.70%	1.37%	1.42%	1.53%

Source: Author's own elaboration based on Eurostat data

Table 3 shows the evolution of household spending on recreational and cultural services as a share of GDP in the four European regions between 2015 and 2022. Northern Europe shows growth until 2019 (1.78% → 2.01%), followed by a decline in 2020 (1.56%) and a partial recovery to 1.88% in 2022. Western Europe sees a slight increase until 2019 (1.42% → 1.48%), but after a decline in 2020-2021 (1.22% → 1.07%), it rebounds to 1.32% in 2022, still below the pre-crisis level. Southern Europe shows the highest share of spending, rising until 2019 (2.03% → 2.13%), falling to 1.60% in 2020, but recovering to 2.09% by 2022. Eastern Europe remains stable, with minimal fluctuations (1.65% in 2015, falling to 1.37% in 2020, rising to 1.53% in 2022). The results confirm the sensitivity of spending to economic shocks and differences between regions, with Southern Europe steadily leading and Western Europe showing the highest volatility.

Figure 2. Evolution of the level of household spending on recreational and cultural services in millions of euros in European Union countries over the reference period (2015-2022)



Source: Author's own elaboration based on Eurostat data

Figure 2 shows total household spending on recreational and cultural services in the EU between 2015 and 2022, rising from €197 billion (2015) to almost €226 billion (2019), reflecting stable demand. There was a sharp drop to €177 billion in 2020 due to economic and social turbulence, followed by a partial recovery in 2021 (€192 billion) and a significant increase in 2022 to over €242 billion. This development confirms the resilience of the cultural and recreational sector as well as the strong consumer demand after the recovery from the crisis period.

Table 4. Evolution of the level of household expenditure on recreational and cultural services per woman employed in the cultural industry in EUR over the reference period (2015-2022)

Region	2015	2016	2017	2018	2019	2020	2021	2022
Northern Europe	17,891	18,851	20,147	20,703	21,502	18,462	20,342	22,889
Western Europe	13,832	14,368	14,386	15,303	16,165	12,378	12,509	15,274
Southern Europe	14,167	14,685	14,829	15,375	15,806	10,388	12,849	17,623
Eastern Europe	6,980	7,143	7,937	8,240	8,598	7,006	8,152	9,621

Source: Author's own elaboration based on Eurostat data

In Table 4, we can observe that Northern Europe shows the highest values, rising from €17,900 (2015) to almost €22,900 (2022), with a dip in 2020 (€18,462) and a recovery thereafter. Western Europe grows from €13,800 to over €16,000, but drops to €12,509 in 2020-2021, reaching €15,274 in 2022. Southern Europe had a stable development until 2019 (EUR 15 806), recovered after a decline in 2020

(EUR 10 388) and surpassed the pre-crisis level (EUR 17 623) in 2022. Eastern Europe remains the lowest, ranging between EUR 6,890 and EUR 9,621, having recovered significantly after a decline in 2020 (EUR 7,005). The data confirms the regional differences, with Southern Europe recording the strongest percentage recovery in the level of spending on the sector after the crisis slump.

Table 5. Statistical analysis (ANOVA, Normality and Homogeneity test) of results for individual variables and groups by region for the study period (2015 - 2022)

	One-Way ANOVA (Welch's)				Normality Test (Shapiro-Wilk)	
	F	df1	df2	p	W	p
% of Females employed in CI	111	3	14.6	<.001	0.967	0.421
Total household expenditures on CI	152	3	14.3	<.001	0.935	0.053

	Homogeneity of Variances Test (Levene's)			
	F	df1	df2	p
% of Females employed in CI	2.53	3	28	0.077
Total household expenditures on CI	7.86	3	28	<.001

Source: Author's own elaboration based on Eurostat data

Table 5 presents the results of three complementary statistical procedures - Welch's one-way ANOVA, the Shapiro-Wilk normality test and the Levene's test for homogeneity of variances - applied to two key variables: the percentage of women employed in the cultural industries and total household expenditure on cultural services. The ANOVA results ($F = 111$ for female employment, $F = 152$ for total expenditure; both $p < .001$) indicate highly significant differences between the four European regions studied, suggesting that each region exhibits a different mean level for both variables. The Shapiro-Wilk test yields $p = 0.421$ for the female employment share and $p = 0.053$ for total expenditure, indicating that neither distribution deviates significantly from normality at conventional significance thresholds (although the dependent variable is borderline). However, Levene's test shows $p = 0.077$ for the female employment share - implying that the assumption of equal variances is not significantly violated - while $p < .001$ for total expenditures confirms the significant heterogeneity of variances across regions. This suggests that Welch's version of the ANOVA is particularly well suited for the analysis of total household expenditure, as it does not depend on the assumption of homoskedasticity. Overall, these findings show that the four regions differ significantly in both the share of women employed in the cultural industries and household cultural expenditures, with only the latter variable showing clear inequality of group variances.

Table 6. Games-Howell test of the variable percentage of women employed in the cultural industries over the study period (2015-2022)

		Northern Europe	Western Europe	Southern Europe	Eastern Europe
Northern Europe	Mean	—	0.0706	0.0892	0.0353
	p-value	—	<.001	<.001	<.001
Western Europe	Mean		—	0.0185	-0.0353
	p-value		—	0.08	<.001
Southern Europe	Mean			—	-0.0539
	p-value			—	<.001
Eastern Europe	Mean				—
	p-value				—

Source: Author's own elaboration based on Eurostat data

Tables 6 and 7 show pairwise comparisons from the Games-Howell post hoc test applied to the percentage of women employed in the cultural industries (Table 6) and to total household expenditures on cultural and recreational services (Table 7). Table 6 shows that the proportion of women employed in the cultural sector in Northern Europe is significantly higher than in Western, Southern and Eastern Europe ($p <$,001 in each comparison). Western and Eastern Europe also differ significantly ($p <$,001), while the contrast between Western and Southern Europe does not always reach statistical significance ($p \approx$,08). This result suggests that Northern Europe stands out with a significantly increased share of women in the cultural workforce, while Eastern Europe holds a lower position, with Western and Southern Europe occupying intermediate positions that may or may not differ significantly from each other. Table 7, below, shows that the Games-Howell analysis of total household expenditures shows that Western Europe exhibits significantly higher expenditures compared to Northern, Southern, and Eastern Europe ($p < .001$ for each paired test). In addition, Southern Europe tends to statistically significantly outspend Eastern Europe ($p < .001$), although differences involving Northern Europe do not always reach significance (p-values approaching .08 or .97). These findings suggest that for cultural expenditure, Western Europe dominates by a considerable margin overall, while Southern Europe maintains a slight lead over Eastern Europe. Northern Europe is somewhere in between, sometimes coming closer to Southern or Eastern Europe, but in absolute expenditure it ends up lagging behind Western Europe.

Table 7. Games-Howell test of the variable total household expenditure (EUR million) on cultural and recreational services over the reference period (2015-2022)

		Northern Europe	Western Europe	Southern Europe	Eastern Europe
Northern Europe	Mean	—	-13.9	-3.76	0.0817
	p-value	—	<.001	<.001	0.97
Western Europe	Mean		—	10.11	13.9541
	p-value		—	<.001	<.001
Southern Europe	Mean			—	3.8403
	p-value			—	<.001
Eastern Europe	Mean				—
	p-value				—

Source: Author's own elaboration based on Eurostat data

Table 8 shows the results of separate linear regressions estimated for each region separately, in which total household expenditure on cultural and recreational services (the dependent variable) is modeled as a function of the percentage of women employed in the cultural industry (a covariate). For each region - Northern, Western, Southern and Eastern Europe - the reported coefficients, significance levels and goodness-of-fit indicators suggest that there is no statistically significant linear relationship between the proportion of women employed in culture and total household expenditure. For example, Northern Europe has an R of 0.174, but the corresponding p-value of 0.681 and negative adjusted R^2 (-0.131) highlights the lack of explanatory power of this single regressor. Similarly, for Western Europe, R^2 is only 0.00545 (adjusted R^2 = -0.16) with p = 0.862, confirming that changes in the female labor force share do not have a noticeable effect on expenditure in the sample. Southern and Eastern Europe show comparable patterns: although Eastern Europe's R is slightly higher (0.388), the p-value of 0.342 remains well above conventional significance thresholds and its adjusted R^2 (-0.094) indicates limited explanatory power. In terms of the estimated coefficients themselves, the intercept of each region is not significantly different from zero, and the estimated slopes for "% of women employed in CI" do not reach statistical significance. Taken together, these findings suggest that within each individual region's eight-year panel (2015-2022), differences in the proportion of women employed in CI do not reliably predict the level of household spending on cultural and recreational services.

Table 8. Analysis of the mutual influence of variables using linear regression by region

		Northern Europe	Western Europe	Southern Europe	Eastern Europe
Northern Europe	Mean	—	-13.9	-3.76	0.0817
	p-value	—	<.001	<.001	0.97
Western Europe	Mean		—	10.11	13.9541
	p-value		—	<.001	<.001
Southern Europe	Mean			—	3.8403
	p-value			—	<.001
Eastern Europe	Mean				—
	p-value				—

Source: Author's own elaboration based on Eurostat data

Table 9 summarizes the Shapiro-Wilk tests of normality for the same variables. While Northern and Western Europe show statistics around 0.937 to 0.945 with p-values above 0.05, Southern and Eastern Europe show slightly lower statistics (0.88 and 0.85). However, the corresponding p-values of 0.19 and 0.095 are still above normal significance levels, indicating that the deviations from normality are not significant enough to invalidate the normality assumption. In fact, there is insufficient statistical evidence to classify the data as non-normal in any of the four regions.

Table 9. Analysis of the mutual influence of variables using linear regression by region

Region	Statistic	p
Northern Europe	0.937	0.577
Western Europe	0.945	0.665
Southern Europe	0.88	0.19
Eastern Europe	0.85	0.095

Source: Author's own elaboration based on Eurostat data

The results contained in this section show significant regional differences and limited predictive power of female employment shares of total cultural expenditure. Although Northern and Western Europe often stand out for higher expenditure or a larger share of female labor force, neither of these variables seems to show a direct linear relationship across regions. Diagnostic checks for normality generally support the appropriateness of standard analytical approaches in this context.

Based on the results of the regression analysis and statistical tests, hypothesis H_0, which states that there is no statistically significant effect between the evolution of the percentage of women employed in the cultural industries and household expenditure on cultural and recreational services, was confirmed. The results of the analysis did not show a consistent and statistically significant relationship between the two variables at the level of the entire sample set or when disaggregated by region.

Conversely, hypothesis H_1, which posited the existence of a statistically significant influence between the proportion of women employed in the cultural industries and household expenditure on cultural and recreational services, was not confirmed. Although some concurrent trends between these variables can be observed in some regions, the analysis did not reveal a causal relationship that was statistically significant for all countries examined.

4. Discussion

The results of the research show significant regional differences in the gender structure of employment in the cultural industries and their impact on household spending on cultural and recreational services in European countries. This chapter offers an interpretation of the empirical data obtained, compares it with the existing literature and identifies broader economic and policy implications.

The results of the analysis suggest that the share of women in the cultural industry alone is not a clear determinant of the level of household expenditure on cultural services. Although Northern Europe consistently has the highest proportion of women in the cultural sector, its spending on culture and recreation is lower compared to Western Europe, which has a lower proportion of women in the sector but higher consumer activity. This discrepancy suggests that other factors, such as overall economic levels, average household income and cultural policy, may have a greater impact on spending levels than the gender structure of employment per se.

Statistical analysis has shown significant differences between regions in Europe. Western Europe maintains the highest absolute spending on culture, while Eastern Europe lags, despite the growing share of women in the sector. This trend may be due to differences in disposable income, consumer preferences or accessibility to cultural services. Southern Europe, which has recovered more quickly from the pandemic than Western and Eastern Europe, shows a strong cultural tradition and high household engagement in cultural consumption.

One of the main limitations of this study is its dependence on available statistical data, which may vary in quality, accuracy and collection methodology between countries. Some data are aggregated at too broad a level, making it difficult to identify more subtle trends and regional specificities. Although the analysis covers a longer time period, it is not possible to fully capture short-term fluctuations in consumer behavior, which may have been influenced by seasonal factors or one-off economic events. Another important limitation is the absence of some variables that could have had a major impact on household spending on cultural and recreational services. Among the most important factors not included in the analysis are the individual income level of households, which directly determines their consumption possibilities, as well as educational level, which may be correlated with higher involvement in cultural activities. An equally important aspect is consumer preferences and lifestyles, which are shaped by national cultural norms and historical traditions in each country.

Given these limitations, future research could focus on a more detailed analysis of the relationship between gender equality, cultural production and the economic performance of the sector. While this study examined the macroeconomic links between the gender structure of employment and household expenditure, further research could provide a more detailed look at the structure of jobs in the cultural industries, particularly the differences between women in managerial positions and artistic production. In addition, it would be useful to complement quantitative research with qualitative studies to better understand households' decision-making mechanisms in spending on cultural services. Analysis of individual and family attitudes towards cultural consumption could provide valuable insights into the factors that lead to higher or lower spending on cultural and recreational services.

Findings show that although a direct linear effect of gender employment structure on household spending has not been confirmed, gender diversity may influence other factors such as innovation capacity, service quality and overall market stability (Oakley & Ward, 2018; UNESCO, 2025). These aspects are relevant for predictive models of economic valuation of firms as they may be important in assessing indirect economic potential and sector stability.

5. Conclusion

This study analyzed the relationship between the gender structure of employment in cultural industries and household expenditure on cultural and recreational services in European countries over the period 2015-2022. Based on a quantitative analysis of the available data, we examined regional differences and assessed whether there is a statistically significant association between these variables. The results showed that although the gender composition of employment in the cultural sector varies across regions, its impact on household expenditure is neither linear nor clearly demonstrable.

The findings confirm that household spending on cultural services is likely to be influenced by broader macroeconomic factors, including overall economic performance, the average purchasing power of the population, and the availability of cultural services. While regions such as Northern and Western Europe experience a higher proportion of women in the sector, their spending trends do not follow the same pattern, suggesting that the gender structure of employment may not be the primary determinant of consumption in this area.

From a methodological point of view, hypothesis H0 (no statistically significant relationship between the share of women in the cultural industries and household expenditure) was confirmed, while the alternative hypothesis H1 (existence of a statistically significant relationship) was not supported by the available data. This suggests that although the gender composition of employment may have an impact on the quality and nature of cultural services offered, its impact on household expenditure itself is limited and mediated by other economic variables.

In practical terms, these findings suggest that policies aimed at promoting gender equality in the cultural industries can have positive social and economic benefits but may not in themselves lead to a direct increase in household spending on culture. If the aim is to increase consumption in this sector, a more comprehensive approach is needed, involving broader economic support for cultural services, increasing access to cultural infrastructure and stimulating demand through targeted financial support for households.

This study provides important inputs for a predictive and dynamic business valuation model by identifying regional differences and confirming the need for a comprehensive consideration of gender diversity as a sectoral factor in economic modelling. For further model development, we recommend exploring the mediated and indirect effects of gender diversity on economic performance to enable even more accurate prediction and assessment of industry risks and opportunities.

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Electric Vehicles: Driving the Transition to Sustainable Transport

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Abstract: Achieving climate neutrality by 2050 requires a fundamental transformation of the road transport sector, replacing internal combustion vehicles with zero-emission technologies. Electric vehicles (EVs) are central to this transition, offering a viable pathway to replace internal combustion vehicles with low- and zero-emission alternatives. The paper provides a comprehensive assessment of the role of electric vehicles in enabling sustainable transport, combining a structured review of international literature with descriptive analysis of data from the Statista portal. The findings demonstrate significant global growth in battery electric vehicles (BEVs), driven by advances in lithium-ion technology, supportive policy measures, and expanding charging infrastructure. Plug-in hybrid vehicles (PHEVs) have also contributed as transitional solutions, while fuel cell electric vehicles (FCEVs) remain limited due to infrastructural and technological barriers. Analysis of worldwide sales, manufacturer market shares, and venture capital investments in e-mobility start-ups by stage and technology further highlights the momentum behind EV adoption. Forecasts that global sales of EV will exceed USD 1 trillion by 2028 confirm their strategic importance for climate policy. The results of the paper indicate that electric vehicles represent a cornerstone of the future transport ecosystem and will play a vital role in achieving sustainable, low-emission mobility worldwide.

Keywords: Sustainability, Transport, Electromobility, Electric vehicles

Introduction

As the global community deals with growing challenges from climate change and seeks ways to achieve sustainable development, the role of electromobility is becoming increasingly important. Electromobility is a key element of the global shift towards sustainability. It is also considered an effective means of decarbonising the transport sector. There will probably be more of these vehicles in our daily lives in the near future. We confront a wide range of dangers in the modern world, including social, economic, and ecological difficulties. As a result, a number of solutions are introduced in an effort to adapt to the evolving reality. Electromobility is a reaction to a number of environmental challenges, including pollution, smog and noise (Wang et al., 2022). The introduction of electric vehicles to the market can contribute to reducing harmful emissions into the environment and to the further development of vehicle design and expansion of their areas of use. Reduced traffic noise will improve the comfort of people living in areas with heavy traffic. Several variables, including as advancements in technology, modifications to road infrastructure, and advancements in power generation techniques, may influence the future of electric vehicles.

In the first part of this paper, we will perform a structured analysis of foreign scientific sources, drawing primarily from international journals to create a theoretical basis for understanding the introduction of electric vehicles in sustainable transport. In the second part of the paper, we will use descriptive statistics to analyse selected data on electric vehicles obtained from the Statista portal, which presents comprehensive and systematically collected indicators on the global status of electric vehicles, worldwide sales, market share by manufacturers, venture capital investment flows and revenue forecasts.

1. Literature Review

Among the most important economic sectors, transport is growing rapidly and has an impact on how businesses operate as well as how citizens live their daily lives. Because of the prolonged usage of fossil fuels, transport activity is one of the primary factors influencing the emission of environmental pollutants.

Given the global issues around greenhouse gas emissions and the need to decrease fossil fuel consumption, electric vehicles are becoming a more significant component of mobility (Kozłowski et al., 2024; Shivkumar et al., 2025). In addition to technology advancements, several nations' pro-environmental regulations, which aim to lower exhaust emissions and enhance urban air quality, are also contributing to their rising popularity. In actuality, transport is responsible for 30.9 % of carbon dioxide emissions, which significantly contributes to global climate change and ozone layer depletion (Wilberforce et al., 2016).

In 2020, the European Commission introduced the European Green Deal, which establishes a legally enforceable goal to reduce greenhouse gas emissions by 55 % by 2030 in order to become Europe climate neutral by 2050 (Fetting, 2020). It is anticipated that all economic sectors, including transport, which has been steadily rising since 1990 and accounts for 20 % of all greenhouse gas emissions in the EU, will help achieve this decrease. Greenhouse gas emissions from the transport industry are predicted to increase by more than 20 % by 2030 and by almost 50 % by 2050 if appropriate action is not taken.

Electric vehicles (EVs) must account for a sizable fraction of new passenger car and commercial vehicle sales in order to accomplish the common goals of reducing greenhouse gas emissions. Furthermore, as the automotive industry employs about 15 million people in Europe and accounts for more than 7 % of the EU's GDP, it is imperative that the EU accelerate the development of infrastructure for electric vehicle charging (Amann et al., 2022).

According to the electric charging strategy, less than 20 % of road traffic will be electric by 2030, while infrastructure to lower traffic-related carbon dioxide emissions will require 30 % of these investments. This is because EV charging will only account for 18 % of the renewable energy sources that will be installed by 2030. By the end of the decade, 42.8 million electric passenger vehicles (including plug-in hybrid electric vehicles, or PHEVs, and battery electric vehicles, or BEVs) should be on the road for 17 % of all vehicles, 4.4 million electric light delivery vehicles for 13 % of all vehicles, and 0.3 million electric trucks for 3.5 % of all vehicles. Regarding chargers, this amounts to 0.1 million for trucks and buses, 0.7 million for light delivery vehicles, and 6.8 million for passenger cars. By 2030, a 55 % reduction in greenhouse gas emissions will require these numbers (Schneider Electric, 2018).

Governments in a number of nations have put in place different incentive programs to encourage the growth of the EV industry in an effort to remove obstacles to public acceptance of EVs. Purchase subsidies, free license plates, unfettered entry, free parking, and consumer tax credit incentives are a few examples of these programs (Song, et al., 2020; He et al., 2023; Chung et al., 2024). One of the main strategies used by governments throughout the world to encourage the growth of the EV industry is the introduction of purchase subsidy policies (Yang et al., 2019). The subsidies strategy has greatly enhanced consumer willingness to buy electric vehicles. However, an over-reliance on large financial backing could make the EV business less sustainable and competitive, which could result in fraud (Harvey, 2020; Mohammadzadeh et al., 2020). Subsidy policy plays a crucial role in promoting the EV industry (Huang et al., 2023).

Generally speaking, electromobility refers to the entirety of the problems associated with using electric automobiles. Both the operational and technical facets of electric vehicles, such as technology and charging infrastructure, are included under this phrase. Social, economic, and legal concerns pertaining to the creation, production, acquisition, and use of electric vehicles are also covered. National, corporate, and societal coordination is necessary to overcome social, financial, and technical obstacles (Sadik-Zada et al., 2023; Zirganos et al., 2022).

Electric cars, e-bikes, e-motorcycles, e-buses, and e-trucks are all considered forms of electromobility. All of the vehicles on the list share the ability to get energy mostly from the electric power grid, energy storage capabilities, and complete or partial electric propulsion (Morgenstern et al., 2022). E-mobility, which includes electric cars, other electric vehicles, and other components of electric transportation, can be described as a complex field.

The potential of electromobility to solve environmental issues, boost energy efficiency, lower costs, encourage technological innovation, and support a more sustainable transportation system makes it significant. Infrastructure is growing and technology is always improving. Reducing greenhouse gas emissions and fighting climate change need the development of sustainable mobility (Haseli et al., 2023). As a result, it is anticipated that electromobility will become more significant in determining the direction of transportation in the future (Lojano-Riera et al., 2023).

2. Methodology

The aim of the paper is to provide an overview of electric vehicles that are paving the way for a global transition to sustainable transport. The paper synthesises findings from the structured literature review and empirical data obtained from the Statista portal.

The research process began with a structured review of the literature, which dealt with the following concepts and terms: environmental pollutants, greenhouse gas emissions, the European Green Deal, climate neutrality, electromobility, forms of electromobility, electric vehicles (EVs), and the potential of electromobility.

Based on this overview, the paper contains an empirical section based on a descriptive analysis of data obtained from the Statista portal, a reputable online statistics platform that aggregates, curates, and publishes reliable and regularly updated datasets covering diverse sectors, including detailed data on electric vehicles.

The analysis focused on several core dimensions, including:

- the evolution of the global stock of electric vehicles by type;
- the worldwide sales trajectory of plug-in electric light vehicles;
- the distribution of plug-in electric vehicle market shares among leading manufacturers;
- the structure of venture capital investments in e-mobility start-ups;
- and global revenue forecasts for electric vehicles.

To ensure scientific accuracy, various proven methods were used in the study, including analysis, synthesis, abstraction, induction, deduction and comparative evaluation. In addition, graphical methods, specifically bar charts, were used to visualise and interpret the data obtained from the Statista portal, thereby increasing the transparency, accessibility and interpretative clarity of the results.

3. Results and Discussion

The dynamic development of electromobility is one of the most important pillars of the transformation of transport towards sustainable mobility. The growing number of electric vehicles (EVs) brings many environmental and economic benefits, but also presents new challenges. In the next part of the paper, we'll examine the global development and spread of electric vehicles as a key way to achieve sustainable transport, using data from the Statista portal. By analysing trends in the number of electric vehicles, worldwide sales, market shares by manufacturers, venture capital investments and expected revenues, we will provide a comprehensive assessment of the ongoing structural transformation in transport.

The group bar chart 1 illustrates the estimated number of electric vehicles in operation worldwide from 2010 to 2024, disaggregated by vehicle type: battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell electric vehicles (FCEVs).

In 2010, the global BEV comprised approximately 20 000 units, while PHEVs numbered around 4 000 units. FCEVs were effectively negligible, with a recorded stock of just 26 units. In the following period, BEVs experienced substantial exponential growth, surpassing 1.2 million units in 2016, reaching 4.8 million in 2019, and rising to 39 million in 2024. This increase can be attributed to advances in lithium-ion battery technology, declining production costs, policy-driven incentives, and the progressive development of charging infrastructure.

PHEVs likewise exhibited significant growth, albeit at a more moderate scale relative to BEVs. Their in-use stock increased from 70 000 units in 2012 to approximately 800 000 units by 2016, attaining 2.4 million units in 2019, and reached 19 million units by 2024. This pattern suggests that PHEVs have functioned as an important transitional technology, bridging the gap between internal combustion and fully electric systems.

FCEVs remain a niche segment of the market. From only 26 units in 2010, their number grew to 77 000 units in 2024. This comparatively slow growth highlights ongoing challenges related to fuel cell infrastructure and technology maturity.

The data reveal a decisive global shift favouring battery electric vehicles as the predominant technology pathway for sustainable and low-emission transport, supported by PHEVs during the transition period. The limited uptake of FCEVs highlights the necessity for further research, policy support, and infrastructure investment to fully realise their potential within a decarbonised transport system.

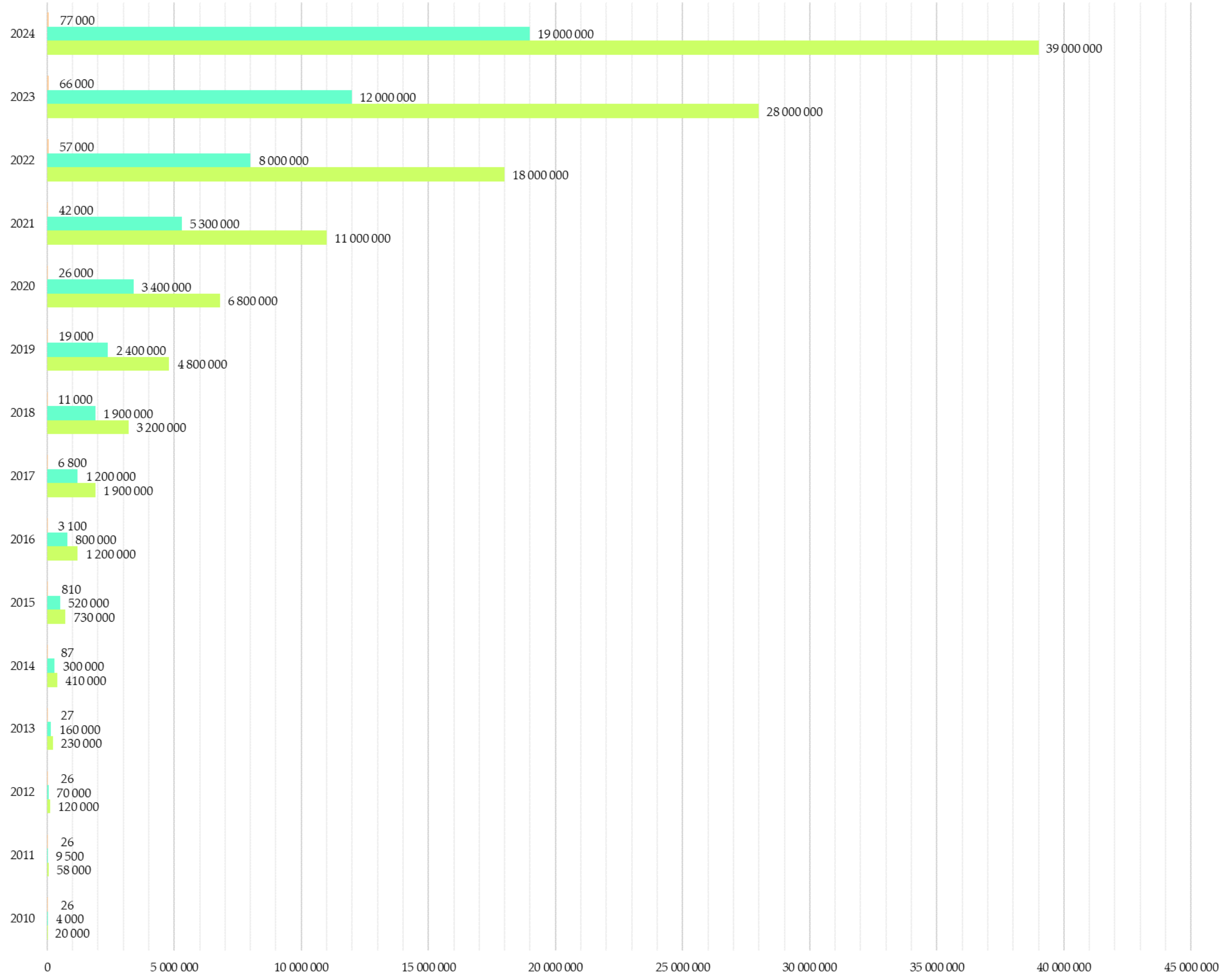


Chart 1. Number of electric vehicles in use by type 2010-2024.

Source: Statista. (2025). *Estimated number of electric vehicles in use worldwide between 2010 and 2024, by type*. https://www.statista.com/statistics/1101415/number-of-electric-vehicles-by-type/

The bar chart 2 illustrates the worldwide sales of plug-in electric light vehicles (PEV) from 2010 through 2024, measured in millions of units. The data, adapted from Statista, captures a remarkable exponential growth trajectory in global PEV adoption over the past decade and a half.

In 2010, global sales of plug-in light vehicles were negligible, at approximately 0.01 million units. From that baseline, annual sales expanded modestly but consistently, reaching 0.78 million units by 2016. Thereafter, adoption accelerated markedly: by 2017, sales exceeded 1.2 million units, doubling to 2.05 million units in 2018 and slightly increasing to 2.09 million in 2019.

Despite modest growth between 2018 and 2019, a significant upsurge occurred from 2020 onwards. Sales increased from 2.98 million units in 2020 to 6.62 million in 2021, an approximate 120 % year-on-year growth, likely reflecting improved market offerings, policy incentives, and heightened environmental awareness. This growth trend continued: sales climbed to 10.22 million units in 2022, and 13.71 million in 2023. The bar chart shows that sales reached 17.51 million units in 2024, highlighting the strong momentum behind the adoption of electric vehicles.

The data compellingly illustrate how plug-in electric light vehicles have moved from niche status to becoming an increasingly mainstream segment of the global automotive market, supporting broader decarbonisation and sustainability objectives.

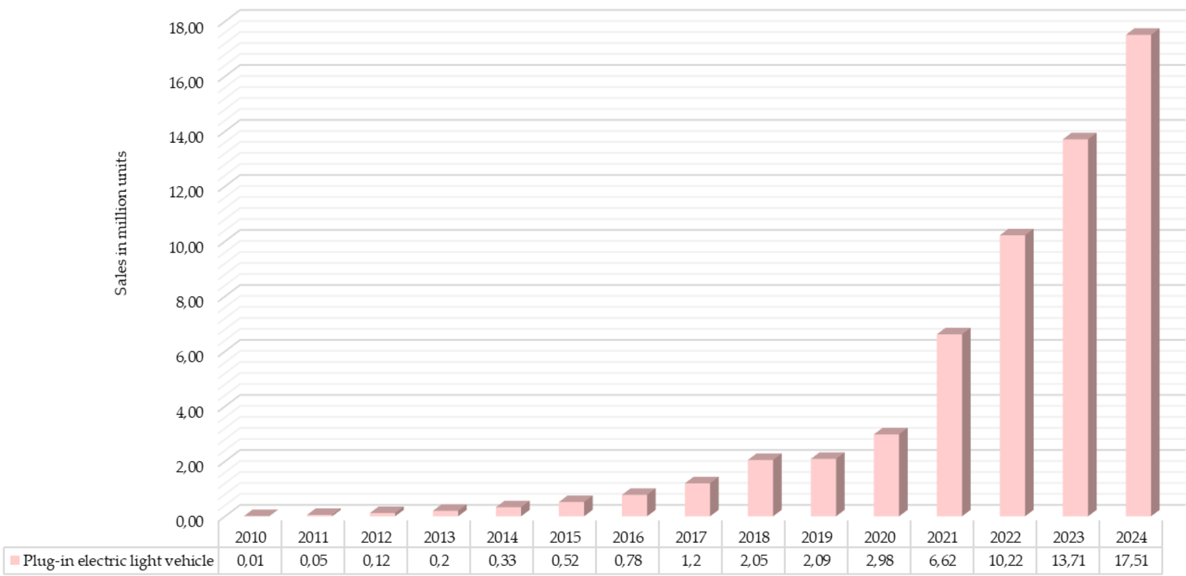


Chart 2. Plug-in electric light vehicle sales worldwide 2010-2024.

Source: Statista. (2025). *Estimated plug-in electric car sales worldwide from 2010 to 2024 (in million units).* https://www.statista.com/statistics/665774/global-sales-of-plug-in-light-vehicles/

The bar chart 3 presents the global market share of plug-in electric vehicle (PEV) sales by manufacturer for the year 2024. In 2024, BYD achieved the largest share of global PEV sales, representing approximately 24.7 % of the total market. Tesla ranked second with a market share of 10.4%. Geely-Volvo Car Group achieved the third largest share with 8.3 %. The Volkswagen Group (VW Group) accounts for 5.7 % of global PEV sales, while Shanghai Automotive Industry Corporation (SAIC) secures a similar share at 5.6 %. The "Others" category, comprising a large number of smaller and regional manufacturers, collectively represents a significant 45.3 % of the market, highlighting the increasingly fragmented and competitive nature of the global PEV sector. The data suggest that while a handful of dominant manufacturers, particularly BYD and Tesla, exert considerable influence, a large proportion of the market remains diversified across numerous other players.

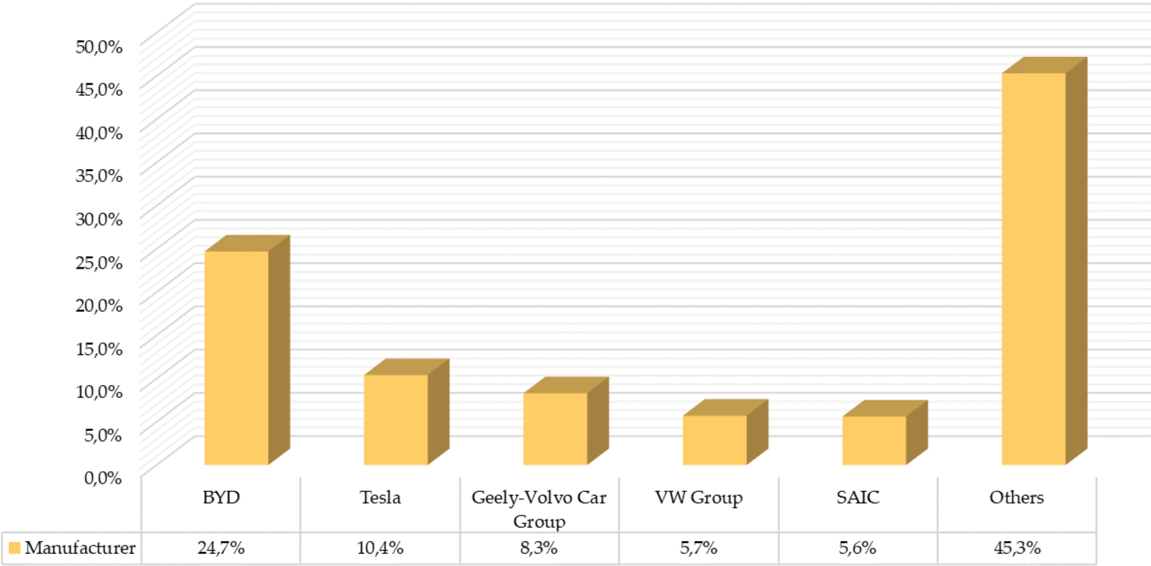
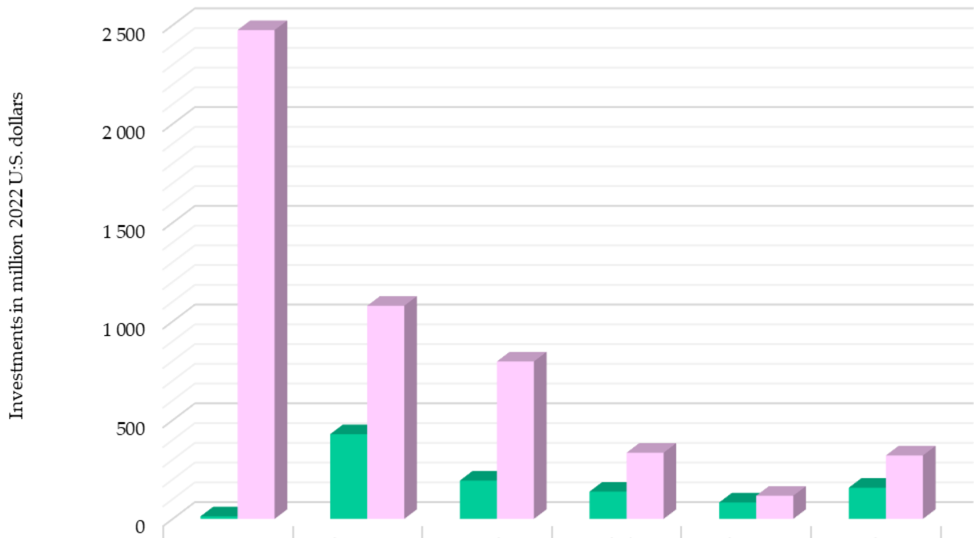


Chart 3. Plug-in electric vehicle market share by manufacturer 2024.

Source: Statista. (2025). *Global plug-in electric vehicle market share in 2024, by main manufacturer*. https://www.statista.com/statistics/541390/global-sales-of-plug-in-electric-vehicle-manufacturers/

The bar chart 4 illustrates the distribution of global venture capital investments in e-mobility start-ups in 2023, differentiated by technology segment and investment stage. In 2023, the car segment attracted the most substantial venture capital funding, with growth-stage investments amounting to approximately USD 2 475 million, compared to only USD 13 million in early-stage investments. The charging infrastructure segment also commanded significant investment, receiving USD 1 079 million in growth-stage funding alongside USD 429 million in early-stage capital. Two- and three-wheeler technologies garnered USD 797 million in growth-stage investments and USD 194 million in early-stage funding, demonstrating notable momentum in emerging markets and last-mile transport applications. Investments in truck, bus, and commercial vehicle technologies reached USD 335 million allocated at the growth stage and USD 138 million at the early stage, suggesting a still-maturing opportunity for electrification in commercial transport. Electric mobility fleet services attracted USD 117 million in growth-stage investment and USD 83 million in early-stage funding, reflecting steady but moderate capital allocation. The “Other” category, encompassing miscellaneous e-mobility start-up activities, accounted for USD 321 million in growth-stage and USD 158 million in early-stage investments.

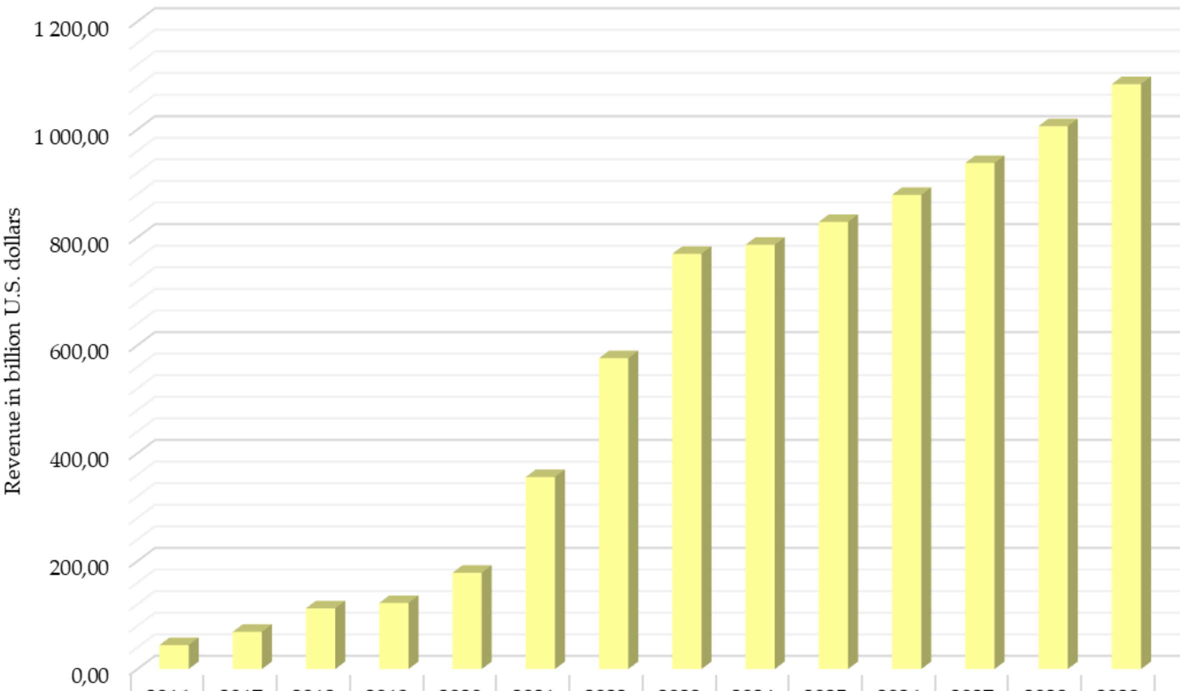


	Car	Charging	Two-/Three-wheelers	Truck, bus, and commercial vehicle	Electric mobility fleet	Other
Early-stage venture capital investments	13	429	194	138	83	158
Growth-stage venture capital investments	2 475	1 079	797	335	117	321

Chart 4. Venture capital investments in e-mobility start-ups by stage and technology 2023.

Source: Statista. (2025). *Global venture capital investments in electric mobility start-ups in 2023, by stage and technology (in million 2022 U.S. dollars).* https://www.statista.com/statistics/1387929/global-venture-capital-investments-in-e-mobility-start-ups-by-stage-and-technology/

The bar chart 5 depicts historical and forecast global revenues from electric vehicle (EV) sales between 2016 and 2029, measured in billion U.S. dollars. In 2016, global EV revenues stood at approximately USD 44.39 billion. This number increased progressively to USD 68.94 billion in 2017, USD 112.5 billion in 2018, and USD 122.4 billion in 2019, reflecting steady early-stage market growth. By 2020, revenues had climbed to USD 178.3 billion. A marked inflection occurred in 2021, when revenue surged to USD 355.8 billion, signalling a phase of rapid market scaling. Forecasts anticipate continued significant expansion, with revenues projected at USD 576.0 billion in 2022, USD 769.4 billion in 2023, and USD 786.2 billion in 2024. Further growth is expected through 2025 (USD 828.6 billion), 2026 (USD 878.6 billion), and 2027 (USD 937.8 billion), surpassing the USD 1 trillion threshold by 2028 (USD 1 006 billion) and reaching USD 1 084 billion by 2029. This growth pattern underscores the increasingly mainstream role of electric vehicles in the global transport sector. The sustained rise through 2029 signals long-term market confidence and structural shifts favouring decarbonised transport systems.



	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Revenue	44,39	68,94	112,5	122,4	178,3	355,8	576,0	769,4	786,2	828,6	878,6	937,8	1 006	1 084

Chart 5. Global electric vehicle revenue forecast 2016-2029.

Source: Statista. (2025). *Global revenue for electric vehicles between 2016 and 2023, with a forecast through 2029 (in billion U.S. dollars).* https://www.statista.com/statistics/271537/worldwide-revenue-from-electric-vehicles-since-2010/

4. Conclusion

Transformation of road transport sector through replacing of internal combustion vehicles with zero-emission technologies is among key challenges to achievement of climate neutrality by 2050. Electric vehicles (EVs) have an important role in the transition towards a low-carbon economy and, more specifically, in the decarbonization of the transportation sector. The increasing penetration of electric vehicles (EVs) reflects the technological advances in electromobility as well as the impact of the policies implemented at the EU and national levels.

The aim of the paper was to deliver a comprehensive overview of how electric vehicles are driving the global transition toward sustainable transport. This aim was achieved by integrating insights from a structured literature review with reliable empirical data obtained from the Statista portal.

Based on the results presented in the paper, we found that the transition toward sustainable and low-emission transport system has positioned electric vehicles (EVs) at the forefront of global decarbonisation strategies. Over the past period, battery electric vehicles (BEVs) in particular have experienced exponential growth, rising from a global fleet of approximately 20 000 units in 2010 to a projected 39 million units by 2024, driven by advances in lithium-ion battery technologies, declining production costs, supportive policy frameworks, and the development of charging infrastructure. Plug-in hybrid electric vehicles (PHEVs) have also expanded, though at a more moderate pace, acting as transitional solutions bridging the gap between conventional combustion engines and fully electric systems. In contrast, fuel cell electric vehicles (FCEVs) have remained a niche segment with limited technological and infrastructure challenges.

Concurrently, global sales of plug-in electric light vehicles have demonstrated remarkable acceleration, growing from virtually negligible levels in 2010 to an estimated 17.51 million units in 2024, reflecting broader societal acceptance and policy momentum. Market share data for 2024 reveal a concentrated landscape led by BYD and Tesla, yet still characterised by significant fragmentation, with nearly half of sales attributed to a diverse group of smaller manufacturers. Substantial venture capital flows into e-mobility start-ups, particularly targeting passenger car technologies and charging infrastructure, further underscore the sector's innovation and growth potential. Global EV revenue forecasts, surpassing USD 1 trillion by 2028, confirm electric vehicles as a central pillar in future transport systems, with profound implications for climate policy.

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Implementation of Industry 4.0 Elements in Selected Service Sectors

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Abstract: This article explores the extent to which small and medium-sized enterprises (SMEs) in Slovakia's Advertising and Market Research, Telecommunications, and Financial Services sectors have adopted the principles of Industry 4.0, which emphasize the integration of digital technologies into business operations. A mixed-methods approach was employed, combining theoretical foundations with empirical data obtained through a structured questionnaire survey. The collected responses were analyzed using statistical methods to assess the level of Industry 4.0 implementation and to identify key influencing factors. The findings indicate varying levels of adaptation across sectors, with the Telecommunications sector demonstrating the highest degree of integration, while the Advertising and Market Research sector lags behind. Although the potential benefits of Industry 4.0 are broadly acknowledged, actual implementation is hindered by financial limitations, technological challenges, and a shortage of qualified human resources. The results provide valuable insights for policymakers and business leaders aiming to foster digital transformation within service-oriented SMEs and suggest that sector-specific barriers may require targeted strategic approaches to support effective adoption.

Keywords: Industry 4.0, SMEs, digital technologies

Introduction

The rapid advancement of digital technologies is fundamentally reshaping traditional business models and serving as the driving force behind the emergence of the fourth industrial revolution, widely known as Industry 4.0. Characterized by the integration of cyber-physical systems, the Internet of Things (IoT), big data analytics, cloud computing, and artificial intelligence into business operations, Industry 4.0 marks a significant shift toward smart and interconnected enterprises. While much of the early discourse around Industry 4.0 has focused on its impact on manufacturing and production industries, its influence is increasingly evident across service sectors as well. Service-oriented enterprises, particularly those in knowledge-intensive and technology-driven domains, are facing mounting pressure to innovate and digitalize their operations in order to enhance competitiveness, efficiency, and customer satisfaction.

This transformation is not confined to large corporations. Small and medium-sized enterprises (SMEs), which constitute a crucial component of most national economies and serve as key drivers of employment and innovation, are likewise compelled to adapt. The transition to Industry 4.0 presents SMEs with substantial opportunities—including enhanced operational agility, improved service delivery, and the development of new business models—but also poses considerable challenges. These include financial limitations, underdeveloped technological infrastructure, and a shortage of digital competencies. Such barriers tend to be even more pronounced in service-oriented sectors, where the intangible nature of offerings and the emphasis on customer-centric processes necessitate a distinct and often more complex approach to digital integration.

This article focuses on SMEs operating in three selected service sectors in Slovakia—advertising and market research, telecommunications, and financial services—to explore how they are adopting and implementing the core elements of Industry 4.0. These sectors were chosen due to their differing levels of technological intensity and digital maturity, providing a diverse landscape for analysis. The objective is to assess the current state of Industry 4.0 implementation within these enterprises, identify the main barriers and enablers influencing the digital transformation process, and highlight sector-specific challenges. Furthermore, the study draws on empirical data gathered through structured surveys to develop practical recommendations that may support SMEs in navigating their path toward successful Industry 4.0 integration. By doing so, this article contributes to a deeper understanding of how digital transformation is unfolding in the service sector context and offers insights that are valuable for policymakers, researchers, and business leaders seeking to foster a more resilient and innovation-driven economy.

1. Literature Review

The ongoing adoption and development of information and communication technologies (ICT) have brought about transformative changes across virtually every sphere of human activity. One of the most significant drivers of societal and economic transformation in recent years has been digitalization. In a broad sense, digitalization refers to the process of converting various types of information—such as textual, audio, or visual—into digital formats that can be stored, processed, and transmitted efficiently (Khan, Khan, & Aftab, 2015). However, despite its widespread use, the concept of digitalization remains multidimensional, and scholarly definitions often diverge in focus, scope, and context.

From an economic perspective, digitalization is defined as the process of transforming traditional economic activities into digital form. This transformation delivers measurable benefits to businesses, employees, and consumers alike. Scholars agree on the generally positive effects of digitalization on economic systems. These effects include reductions in unemployment, lower operational costs, and improved quality of life (European Commission, 2020; Strohmeier et al., 2021). For enterprises, the digital transformation of business operations enables increased productivity, lower costs, and greater efficiency across internal processes. Digital tools and platforms also support more effective customer communication and facilitate better understanding of consumer preferences and needs (Bughin et al., 2018). In addition, digitalization fosters innovation by enabling the development of new products, services, and delivery channels that respond more dynamically to market demand. The integration of digital technologies allows for real-time data collection and analysis, supporting faster and more informed managerial decision-making. Furthermore, digitally enabled businesses can achieve higher levels of scalability, allowing them to expand operations and enter new markets with greater ease. Cloud computing and automation also reduce the need for physical infrastructure and manual labor, freeing up resources for strategic growth (Eurostat, 2021). Importantly, digitalization enhances transparency and traceability in supply chains, contributing to improved corporate governance and sustainability practices (Loebbecke & Picot, 2015). These factors together create a more competitive and resilient economic environment, particularly for small and medium-sized enterprises seeking to thrive in increasingly digital ecosystems. As such, digitalization is not only a technical upgrade but also a strategic imperative for long-term economic viability and growth.

Rapid advances in digital technologies have made services more accessible, user-friendly, and customizable. Consumers now expect real-time access to a wide range of services from virtually any location. One of the critical enablers of this evolution is automation, which allows companies to streamline routine tasks, reduce operational costs, and improve overall productivity (European Commission, 2023; OECD, 2022). However, the degree of digital adoption varies significantly across different service sectors and is influenced by technological readiness, market demand, and strategic priorities (Rachinger et al., 2019).

The financial and banking sectors exemplify areas where digitalization has had profound effects. As early as the 1990s, European banks began introducing electronic banking services, laying the groundwork for what would become the current era of digital finance (Zavolokina et al., 2016). Since then, financial institutions across Europe and globally have adopted various digital solutions to streamline operations, enhance customer service, and increase efficiency. In recent years, fintech companies have played a transformative role, introducing continuous innovations in payment systems and financial service delivery. Mobile banking applications now allow clients to manage their finances without visiting physical branches, and the traditional banking model has evolved from in-person transactions to self-service ATMs, telephone banking, and ultimately, to digital platforms such as internet and mobile banking (European Central Bank, 2023). Emerging technologies like blockchain, decentralized finance (DeFi), and cryptocurrencies are poised to bring about the next wave of digital innovation in banking (Zetzsche et al., 2020).

Telecommunications is another sector that has been deeply reshaped by digitalization. The evolution from legacy voice-based networks to modern, broadband-driven infrastructure reflects a dramatic shift in the way communication services are delivered. Today's telecommunications systems are built upon high-capacity, data-centric networks that not only support voice but also enable a broad spectrum of digital communication services, often accessed through smartphones and other smart devices (European Telecommunications Network Operators' Association [ETNO], 2023). The shift toward data-driven communication has not only improved connectivity but also laid the foundation for advanced applications such as video conferencing, cloud services, and IoT platforms.

Closely tied to developments in telecommunications is the transformation of advertising and marketing. As communication channels have become increasingly digital, marketing strategies have had to adapt accordingly. Digital marketing now plays a pivotal role in business visibility and customer engagement. Consumers spend more time online than ever before, and businesses must compete for attention through a diverse array of digital platforms (Tiago & Veríssimo, 2014). However, this shift has introduced new competitive pressures, especially for SMEs. Large international digital marketplaces such as Temu, Shein, or Allegro invest heavily in online advertising, often outspending and overshadowing smaller domestic firms. This trend not only displaces local businesses from key advertising positions but also inflates advertising costs, which rose by approximately 20% year-on-year due to increased demand for digital ad space (IAB Europe, 2023).

These sectoral case studies illustrate the complexity and variability of digitalization across the service economy. While the opportunities associated with Industry 4.0—such as automation, real-time data analysis, and artificial intelligence—are widely recognized, their practical implementation remains uneven. Key barriers include limited access to funding, technological infrastructure gaps, and insufficient digital literacy, particularly among SMEs (PwC, 2022). Furthermore, the benefits of digital transformation may not be evenly distributed across sectors or regions, necessitating policy interventions that address structural inequities and provide targeted support (European Commission, 2021).

2. Methodology

The article used a quantitative research design to examine the degree of Industry 4.0 implementation among small and medium-sized enterprises (SMEs) in Slovakia, focusing on three selected service sectors: telecommunications (NACE 61), financial services (NACE 64), and advertising and market research (NACE 73). Data collection was conducted through a structured questionnaire based on the Warwick University Readiness Assessment Model, which assesses digital transformation in key business functions including operations, customer interaction, organizational structure, and technological infrastructure.

RQ: Is there a significant difference between the service sectors in which the surveyed enterprises operate and the level of implementation of Industry 4.0 elements, as assessed based on Model Warwick University Readiness Assessment?

H1: There is a statistically significant difference in the level of implementation of Industry 4.0 elements among enterprises depending on the service sector in which they operate.

The collected data were subjected to rigorous statistical analysis, including descriptive statistics to profile the sample and summarize implementation trends, one-way analysis of variance (ANOVA) to test for differences across sectors, and the Mann-Whitney U-test as a non-parametric alternative for verifying results in the case of non-normal distribution of variables. The primary research objective was to assess whether statistically significant differences exist in the level of implementation of Industry 4.0 components depending on the sectoral affiliation of the surveyed enterprises. The study further aimed to contribute to the existing body of literature by identifying sector-specific digitalization patterns and highlighting potential gaps or bottlenecks that may hinder the adoption of advanced technologies in service-oriented SMEs.

A total of 115 valid responses (telecommunications - 32 responses, financial services - 43 responses, advertising and market research - 40 responses) were obtained and analyzed. Enterprises were selected using purposive sampling, with an emphasis on ensuring adequate representation of each of the three target sectors. The questionnaire consisted of both closed-ended and scaled questions, allowing for the quantification of readiness levels across the evaluated dimensions. The Warwick model's structure enabled aggregation of responses into a composite "total score," representing the overall degree of Industry 4.0 implementation.

Before conducting inferential statistics, data were tested for normality using the Shapiro-Wilk test. Since the assumption of normal distribution was violated in several variables, the study proceeded with non-parametric testing methods, ensuring robustness and reliability of the results. The methodological approach was designed to ensure objectivity, reproducibility, and analytical depth. By combining descriptive and inferential techniques, the study not only quantified the state of Industry 4.0 implementation but also provided statistically grounded insights into inter-sectoral differences within the Slovak service economy.

3. Results

In the subsequent section of the article, the obtained results will be subjected to detailed analysis. Given that the analysis includes three distinct service sectors, the relationship between a continuous variable (the overall level of Industry 4.0 implementation, referred to as the "total score" in statistical graphs) and three or more categorical groups (sectors) was examined using a one-way analysis of variance (ANOVA). The results of this analysis are presented in the following figure. This method allows us to determine whether statistically significant differences exist in the mean levels of Industry 4.0 implementation across the selected industries. A statistically significant outcome would indicate that at least one sector demonstrates a markedly different degree of adoption, thereby supporting the hypothesis that the nature of the service sector influences the extent of digital transformation.

Kruskal-Wallis

	χ^2	df	p	ε^2
Celkové skóré	18.0	2	< .001	0.158

Pairwise comparisons - Celkové skóré

		W	p
Reklama a prieskum trhu	Finančné služby	5.472	< .001
Reklama a prieskum trhu	Telekomunikácie	4.703	0.003
Finančné služby	Telekomunikácie	−0.843	0.822

Figure 1. Statistical evaluation of the relationship between industry and level of Industry 4.0 implementation **Source:** Own processing

Based on the Kruskal-Wallis test, we can conclude that the differences among the service sectors in terms of the overall level of Industry 4.0 implementation are statistically significant ($p < 0.05$), with a medium effect size ($\varepsilon^2 > 0.140$). When comparing specific pairs of industries, the post hoc analysis indicates that there is a statistically significant difference between the Advertising and Financial Services sectors ($p < 0.05$), as well as between the Advertising and Telecommunications sectors ($p < 0.05$). Conversely, no statistically significant difference was found between the Financial Services and Telecommunications sectors. These results suggest that the nature of the industry significantly influences the degree of Industry 4.0 adoption, particularly in areas with varying degrees of technological intensity and innovation focus.

To further investigate the magnitude and direction of these differences, the Mann-Whitney U-test was employed for pairwise comparisons. This non-parametric method is appropriate for identifying significant differences in ordinal or non-normally distributed data. The use of this test allows for a more nuanced understanding of how specific sectors differ in their approach to digital transformation. Identifying these differences is crucial for designing tailored support policies and strategic interventions. The findings also underscore the importance of sector-specific readiness and investment capacity as key drivers of Industry 4.0 adoption.

Independent Samples T-Test

		Statistic	p	Mean difference	SE difference		Effect Size
Celkové skóré	Mann-Whitney U	436	< .001	−0.600		Rank biserial correlation	0.493

Note. H_a $\mu_{\text{Reklama a prieskum trhu}} \neq \mu_{\text{Finančné služby}}$

Figure 2. Mann-Whitney U-test between Financial Services and Advertising and Market Research industries implementation
Source: Own processing

There is a statistically significant medium-sized difference between the Advertising and Financial Services sectors (r = 0.493), with a mean difference in the achieved level of Industry 4.0 implementation of 0.60. Similarly, a statistically significant medium-sized difference exists between the Advertising and Telecommunications sectors (r = 0.458), with a mean difference in implementation level of 0.50. These findings suggest that enterprises operating in the Advertising sector are significantly less advanced in adopting Industry 4.0 elements compared to their counterparts in the Financial Services and Telecommunications sectors.

Independent Samples T-Test

		Statistic	p	Mean difference	SE difference		Effect Size
Celkové skóré	Mann-Whitney U	347	< .001	−0.500		Rank biserial correlation	0.458

Note. H_a $\mu_{\text{Reklama a prieskum trhu}} \neq \mu_{\text{Telekomunikácie}}$

Figure 3. Mann-Whitney U-test between Telecommunications and Advertising and Market Research industries
Source: Own processing

This outcome can be interpreted through the lens of sector-specific characteristics and operational demands. The Financial Services sector, due to its regulatory environment, competitive dynamics, and data-intensive operations, has long been an early adopter of advanced digital technologies such as automation, artificial intelligence, and blockchain. Financial institutions are often compelled to invest in robust digital infrastructures to ensure compliance, security, and efficient customer service delivery. Similarly, the Telecommunications sector, driven by constant technological innovation and the need for high-speed connectivity, has integrated numerous Industry 4.0 technologies—such as Internet of Things (IoT), machine learning for network optimization, and predictive maintenance—into its core processes.

In contrast, the Advertising sector, although digitally active in customer engagement and marketing automation, appears to lag behind in the systemic and operational integration of Industry 4.0 technologies. While digital advertising platforms and data analytics tools are widely used, the structural implementation of technologies such as cyber-physical systems, autonomous decision-making systems, or digital twins is relatively limited. This may reflect both a lower perceived necessity for full-scale digital transformation in operational processes and a difference in investment capabilities or strategic orientation.

The observed differences emphasize the importance of tailoring digital transformation strategies to the unique needs and readiness levels of each sector. Policymakers and stakeholders supporting digital innovation should consider these discrepancies when designing financial incentives, training programs, or regulatory frameworks. Additionally, the findings reinforce the argument that Industry 4.0 is not a one-size-fits-all solution but rather a complex, sector-dependent process that requires differentiated approaches for successful and sustainable implementation.

4. Discussion

The article provides empirical evidence confirming the existence of statistically significant differences in the extent of Industry 4.0 implementation among enterprises operating in different service sectors, thereby confirming the initial hypothesis (H1). Specifically, enterprises in the advertising sector show a significantly lower level of Industry 4.0 implementation compared to the financial services and telecommunications sectors, as evidenced by the results of the Kruskal-Wallis and Mann-Whitney U tests.

These findings highlight substantial disparities in the course of digital transformation across different sectors. Sectors characterized by high technological intensity, strict regulatory requirements, and extensive data-driven operations tend to adopt Industry 4.0 elements more rapidly. This trend is particularly evident in the financial services sector, where the demand for automation, data security, regulatory compliance, and enhanced customer service creates favorable conditions for the adoption of advanced digital technologies such as artificial intelligence and blockchain.

Similarly, the telecommunications sector's relatively advanced Industry 4.0 integration can be attributed to its intrinsic reliance on continuous technological innovation, network optimization, and predictive maintenance. These demands align closely with Industry 4.0 paradigms, including the Internet of Things (IoT) and machine learning applications, which support real-time analytics, proactive infrastructure management, and the development of intelligent networks capable of autonomous adjustment and fault mitigation.

In contrast, the advertising sector, while actively utilizing digital tools for campaign management and consumer interaction, appears to lag behind in the broader, system-wide implementation of Industry 4.0 technologies. This may be due to the sector's traditionally lower capital intensity, project-based business models, and a focus on creative outputs over operational automation. While digital marketing platforms and data analytics tools are commonly adopted, the integration of more complex technologies—such as digital twins, autonomous systems, or cyber-physical infrastructure—is relatively limited.

The medium effect size identified in the analysis points to both statistical significance and practical relevance, underlining the real-world implications of sectoral differences in Industry 4.0 readiness. These differences call for a differentiated strategic approach to digital transformation. A uniform model for technological development may fail to address the unique structural, strategic, and cultural characteristics of individual industries. Instead, transformation frameworks should reflect sector-specific needs, capabilities, and maturity levels.

Moreover, the results suggest that policy makers, innovation support agencies, and industry associations should take these sectoral nuances into account when designing interventions such as funding schemes, training programs, or regulatory adjustments. Targeted support measures could help sectors with lower levels of Industry 4.0 adoption—like advertising—overcome barriers related to cost, knowledge, and strategic alignment.

Future research could expand upon these findings by exploring the internal dynamics within individual sectors, identifying micro-level differences in adoption behavior among small, medium, and large enterprises. Longitudinal studies may reveal how Industry 4.0 adoption evolves over time in response to market shifts or technological advances. Additionally, qualitative studies could uncover latent cultural, managerial, and organizational factors that influence digital transformation pathways, offering a more nuanced understanding of both progress and resistance in the implementation of Industry 4.0.

5. Conclusion

The present analysis conclusively demonstrates that the degree of Industry 4.0 implementation varies significantly across service sectors, with the Financial Services and Telecommunications sectors exhibiting higher levels of adoption compared to the Advertising sector. These differences can be attributed to the distinct operational imperatives, technological demands, and strategic orientations that characterize each sector.

This article underscores the critical importance of developing differentiated digital transformation strategies that are sensitive to sector-specific contexts, rather than adopting uniform approaches. Such tailored strategies can inform policymaking, resource allocation, and capacity-building initiatives designed to foster Industry 4.0 adoption more effectively. The results of this study also carry important implications for enterprise management. Companies operating in sectors with lower digital maturity should assess their internal capacities, identify barriers to digital adoption, and formulate strategic roadmaps that align with their specific business models and customer expectations. This may involve prioritizing investments in digital infrastructure, enhancing digital competencies among staff, or rethinking organizational structures to better support innovation.

In sum, acknowledging and addressing the unique challenges and opportunities faced by different service sectors is imperative for promoting sustainable digital transformation, enhancing industrial competitiveness, and facilitating innovation in an increasingly digitized economic environment.

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Circular Economy Business Models from the Perspective of Economic, Environmental and Implementation Determinants

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Abstract: The transition to a circular economy (CE) requires a detailed understanding of circular business models (CBMs) and the identification of their characteristic elements. This study addresses this challenge by analysing 28 models, grouped into four typological categories based on shared features. The aim of the pilot survey was to determine which economic, environmental and implementation characteristics are most frequently represented within each model group. Through qualitative content analysis, the study systematically quantified the occurrence of 21 characteristic elements across three dimensions. The findings reveal that, while cost reduction and resource efficiency are prevalent across all models, each typological group demonstrates distinctive features – technology-oriented models emphasise risk reduction and operational resilience; systemic models highlight cooperative synergies and adaptability; product-centric models focus on reuse and material retention; and access-based models promote behavioural change in consumption. Despite these benefits, significant barriers were identified, particularly logistical complexity, organisational resistance, and low consumer acceptance. The article thus supports the assertion that the development of CBMs requires differentiated strategies that reflect the structural specificities of individual model types, as well as systemic support, capacity development, and cultural transformation in favour of sustainability.

Keywords: circular economy, circular business models, systemic innovation,

Introduction

The circular economy (CE) represents a systemic approach to economic development designed to generate benefits for business, the environment, and society alike (Dragomir, 2023). In contrast to the traditional linear model of "take–make–dispose" (Masi et al., 2017; Arranz et al., 2024), the CE places emphasis on aligning economic growth with environmental protection (Jain et al., 2024; Arroyabe et al., 2024), thereby steering society towards greater sustainability (Dragomir, 2023). CE can be understood as a paradigm for a new economic transformation within the context of green growth, aiming to restructure the economy into a sustainable economic model (Pesor et al., 2024).

1. Literature Review

CE is grounded in the utilisation of principles such as reuse, repair, refurbishment, remanufacturing, recycling, and the development of new business models based on innovative services (Amato, 2024; Hossain et al., 2024; Masi et al., 2017). It encompasses not only a technical and engineering framework for new solutions but also a broader socio-economic transformation (Masi et al., 2017). Its implementation necessitates cross-sectoral coordination among actors, the integration of digital technologies (e.g. cloud computing, artificial intelligence, big data analytics) (Arroyabe et al., 2024), and a sensitive approach to social, cultural, and regulatory contexts (Kannan et al., 2024; Jain et al., 2024; Pesor et al., 2024).

The core objectives of the circular economy, embedded in a fundamental shift in the management of natural resources, production, consumption, and end-of-life treatment of products, include: waste minimisation and prevention, efficient resource use, and the extension of product lifespans (Dragomir, 2023; Hossain et al., 2024). These aims are intertwined with the promotion of economic sustainability and business competitiveness, innovation and technological advancement, job creation and social inclusion, and changes in consumer behaviour and consumption patterns (Laubscher & Marinelli, 2014; Jain et al., 2024).

Circular Business Models (CBMs) serve as the fundamental mechanism for implementing CE principles at the enterprise level. They can be defined as a set of organisational, technological, and strategic practices through which a business creates, delivers, and captures value based on closed, slowed, or shared material and energy flows (Corvellec et al., 2021). CBMs are typically linked to product and process innovations, frequently require cooperation across supply chains (Arranz et al., 2024), and are associated with the development of specific organisational capabilities (Bocken et al., 2022; Hofmann & Knyphausen-Aufseß, 2022). They may be conceptualised as a vehicle for transitioning towards sustainable consumption by reshaping production practices and reducing consumption behaviours (D'Amato & Korhonen, 2021; Das, 2024; Averina et al., 2022). The foundational principles of CBMs involve managing material flows through strategies—primarily the R-strategies (Kirchherr et al., 2017; Reike et al., 2018). The Ellen MacArthur Foundation has identified six strategic categories within the ReSOLVE framework: Regenerate, Share, Optimise, Loop, Virtualise, and Exchange (Ellen MacArthur Foundation, 2015, as cited in Woldeyes et al., 2025). These strategic archetypes can be combined with specific business approaches. An alternative perspective is provided by the European Commission (2020, 2021), which highlights key aspects contributing to sustainability: product longevity, shared models and product-as-a-service (PaaS), recycling and reverse logistics, reduced carbon and environmental footprint, a ban on the destruction of unsold goods, ecological design, and digital solutions. This approach does not offer a closed typology but rather identifies preferred business practices by sector and waste generator. Its emphasis lies more on strategic orientation and policy instruments, particularly within production chains.

Currently identified CBMs do not constitute an exhaustive list. Their practical application may involve hybrid combinations of fundamental models and allow for the integration of new principles. The applicability of specific CBMs relies on the cooperative functioning of economic and environmental principles. The aim of this article was to identify typical characteristics of CBMs in terms of their economic and environmental benefits, as well as the challenges encountered during implementation. Simultaneously, we sought to conduct a systematic comparison based on the typological classification of models, enabling the identification of differences in the profiles of specific CBM groups. To achieve this goal, a qualitative and quantitatively supported analysis was carried out, drawing on secondary data obtained from professional publications on the circular economy and its associated busness models.

2. Methodology

The research was based on academic and practitioner-oriented publications, published between 2014 and 2024, documenting concrete applications of CBMs in business settings. Using qualitative content analysis, 28 examples of CBMs were identified and examined, with each model treated as a distinct unit of analysis. From the analysed studies, model characteristics were systematically extracted and grouped into three dimensions: economic characteristics, environmental characteristics, and implementation challenges. Behavioural elements of each characteristic were further clustered into overarching categories based on content similarity.

A. Economic Characteristics:

- Cost reduction – lowering costs, saving on raw materials and energy, improving input efficiency.
- Stable or recurring revenues – stable income streams, long-term contracts, reduced dependence on product sales, long-term customer relations.
- Preservation or enhancement of product value – maintaining product value, extending the economic cycle.
- Access to new revenue sources – new markets, secondary income streams, revenue from recycled materials.
- Risk reduction and increased resilience – mitigating price volatility risks, supply chain stability, reduced dependency on primary resources, decreasing implementation uncertainty.
- Other specific and contextual benefits – high upfront costs, reputational gains, skill development.
- Improved return on assets and investments – increased component-level returns, effective asset utilisation.

B. Environmental Characteristics:

- Efficient resource use – higher material efficiency, reduced raw material consumption, material and space savings, energy and water efficiency.
- Reduction of environmental burden – waste reduction, waste prevention, emission reduction, reduced carbon footprint, lower demand for new products.
- Closing material loops – recycling, preservation of component value, collection and reuse.
- Lifecycle management – extended product lifespan, lifecycle prolongation, control over lifecycle phases.
- Adaptability and systemic change – optimisation of material flows, acceleration of environmental innovations, application of CE principles in operations.
- Environmental effects – environmental gains due to institutional reforms, restoration of ecosystem services, enhanced circulation efficiency within the value chain, improvement of biodiversity.

C. Implementation Challenges:

- Institutional and regulatory challenges – complex legal structures, regulatory barriers, institutional resistance.
- Technological and innovation challenges – technological readiness, technical complexity, design and modularity, dependency on digital infrastructure.
- Economic and financial barriers – high costs, low returns, complex contractual conditions.
- Organisational and competence-related barriers – need for organisational restructuring, skills shortages, requirement for cooperation between design and management, unclear success metrics, lack of trust among stakeholders.
- Consumer and behavioural barriers – low customer acceptance, unwillingness to pay for repairs, stigmatisation of used products.
- Logistical and operational challenges – costly sorting, complex logistics, unpredictable reverse flows, infrastructure intensity, dependence on consistent access to recycled inputs.

Quality and safety concerns – quality of input materials, production safety, risk of greenwashing.

Based on the frequency of characteristic elements observed across the models, the study identified key influencing factors. CBMs were subsequently categorised into four main groups according to their functional orientation. For each group, a profile matrix was constructed to quantify the frequency of each characteristic. Each characteristic element was counted only once per model, focusing on its occurrence across models. The frequency of characteristic elements within a CBM group was then converted to relative values (%), enabling inter-group comparisons to uncover dominant features or weak points of specific CBM categories. This methodology thus combines the strengths of systematic qualitative analysis with quantitatively grounded descriptive comparison.

A limitation of this study is the limited number of analysed models. Accordingly, the presented analysis should be regarded as a pilot study aimed at identifying core CBM characteristics and exploring their alignment with distinct model types.

3. Results

The analysis of identified CBMs revealed varying frequencies of economic, environmental, and implementation characteristics across the examined sample. (Figure 1) From the total number of occurrences recorded across the analysed models, only those characteristics were selected that recurred across multiple model groups and exceeded a relevant frequency threshold. It should be noted that some characteristics appeared multiple times within a single model in different forms.

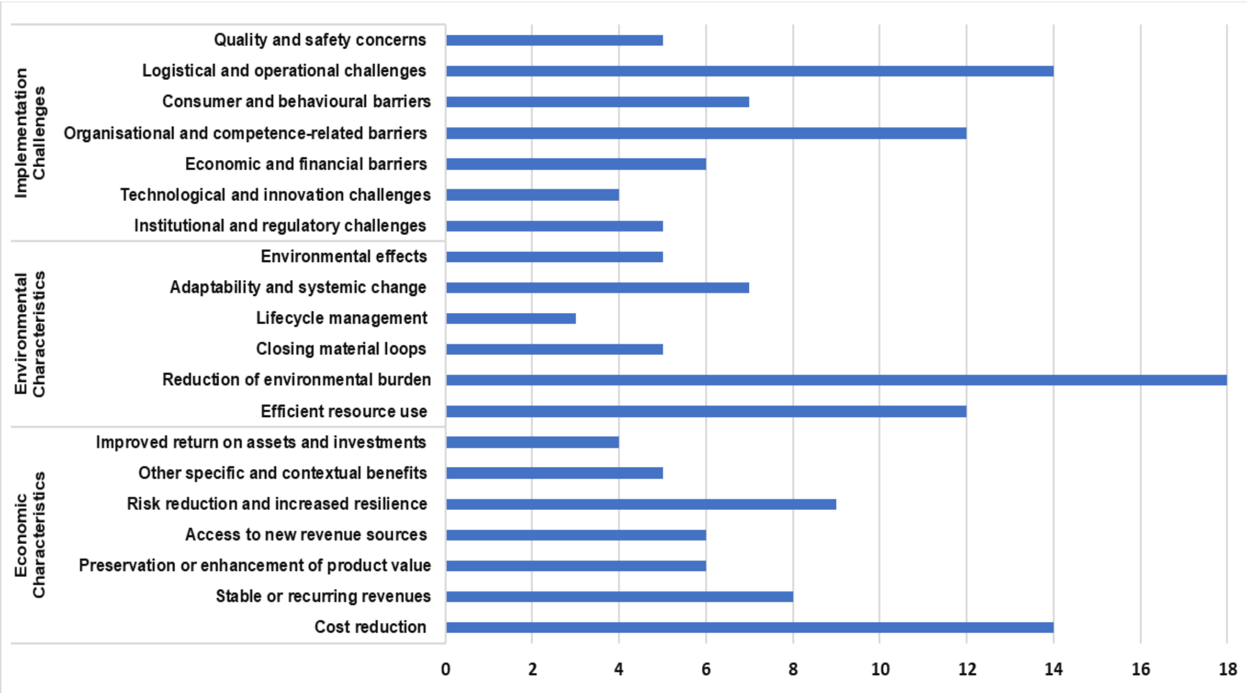

Figure 1. Identified characteristic elements of CBM

Source: own processing

Among economic benefits, the most dominant element was cost reduction, present in 27% of cases. This outcome highlights the primary motivation for businesses adopting CBMs—namely, increasing the efficiency of input use and minimising costs related to raw materials, energy, and logistics. Models focused on product reuse, repair, remanufacturing, and recycling generate substantial savings in production and distribution processes. Other significant economic factors include risk reduction and enhanced resilience, with a 17% occurrence rate, reflecting efforts to diversify inputs, reduce dependency on primary raw materials, and buffer price volatility. The third key element was stable or recurring revenues, observed in 15% of cases, indicating a preference for models that enable long-term customer relationships and stabilise income streams.

Among environmental benefits, the most prominent element was reduction of environmental burden, confirmed in 36% of cases. This characteristic underscores the CBM objective to reduce the overall environmental impact through waste prevention, emission reductions, and a lowered ecological footprint. It is typically fulfilled by extending product lifespans and replacing linear consumption with circular practices. Also significant was efficient resource use, present in 24% of models, which refers to the optimisation of material flows and reduced energy and water consumption. CBMs aim to maximise the value derived from each unit of input, which results in reduced material and energy loads per unit of output. A third key element was adaptability and systemic change, occurring in 14% of models, signalling the transformative potential of CBMs in terms of organisational and technological innovation. Their implementation integrates operational and environmental goals and fosters systemic innovation across the value chain.

The most frequently observed implementation challenge was logistical and operational issues, with a 26% share, reflecting the complexity of managing physical product flows within circular systems. This includes reverse logistics, sorting, infrastructure for remanufacturing and recycling. Another identified challenge was organisational and competence-related barriers, with a 23% occurrence, expressing the need for changes in internal structures, the acquisition of new skills and capabilities, and cross-functional collaboration. The adoption of CBMs often entails a shift in business models, performance evaluation systems, and integration of design and management. A third significant element was consumer and behavioural barriers, observed in 13% of cases, representing psychological and cultural obstacles to accepting products from secondary markets, repaired goods, or shared-use systems.

The research clearly confirms that economic efficiency, environmental burden reduction, and organisational transformation constitute the three foundational pillars for CBM application. While cost and footprint reduction form the basis of their appeal, their wider adoption is contingent upon significant transformation capacities—technological, organisational, and consumer-related. The findings also suggest that successful implementation depends not only on environmental convictions but, crucially, on the ability to manage complex logistics, internal capacities, and external market responses.

Based on commonalities in their described focus, the CBMs were divided into four typological groups:

- Access and Utilisation Models
- Product-Centric Circularity Models
- Systemic and Networked Models
- Technology-Enabled Circularity Models

3.1. Characteristics of Access and Utilisation Models

The Access and Utilisation Models (AUM) group includes five models based on the principles of sharing, prioritising functionality over ownership, and the "product-as-a-service" concept. Their primary goal is to increase product utilisation, reduce demand for new goods, and simultaneously enhance economic returns.

Within economic benefits, cost reduction was the most significant element, found in 33% of the models. It represents a key economic factor manifested through lower operational costs achieved via the efficient use of existing products, reduction of redundant inputs, and logistics optimisation. This feature is typical of rental, sharing, and product-service systems, where investment is made in functionality rather than ownership. An equally common feature (33%) was stable or recurring revenues, reflecting AUM's ability to generate predictable and ongoing income. Long-term customer relationships are maintained through service agreements, subscriptions, or digital platforms, which facilitate continuous value delivery instead of one-time sales. A supplementary economic element was increased return on assets and investments, appearing in 22% of cases, indicating a high level of asset utilisation. AUMs enable repeated use of the same product by multiple users, thereby increasing the economic efficiency of returns and reducing the need for new production.

Among environmental benefits, efficient resource use was dominant, occurring in 38% of models. This reflects the significant contribution of AUM to material, energy, and space savings by maximising the utilisation intensity of existing products. Sharing among users decreases redundancy and overproduction, leading to marked environmental benefits through the reduced consumption of natural resources. Also relevant were reduction of environmental burden and lifecycle management, each appearing in 25% of models. The former reflects benefits such as waste reduction, emission prevention, and overall carbon footprint mitigation. Product-as-a-service approaches reduce the demand for new goods and, hence, emissions related to manufacturing and logistics. Lifecycle management emphasises AUM's ability to extend product longevity through maintenance and repair while monitoring functionality throughout the operational phase. This aspect is critical to the model's sustainability by preventing premature product disposal.

The most frequently identified implementation challenge was institutional and regulatory issues, present in 30% of the models. This refers to difficulties arising from legal frameworks, ownership relations, and accountability in service-based product provision. Legal uncertainty surrounding service models, sharing, and licensing can be a major obstacle to broader deployment. Further challenges include economic and financial barriers and organisational and competence-related barriers, each appearing in 20% of models. Economic barriers reflect the need for higher initial investments in digital infrastructure, platform development, and quality assurance, including reverse logistics. Organisational challenges highlight difficulties related to internal process change, lack of specialised skills, and the need for interdisciplinary collaboration (e.g., between design, IT, and service teams).

Access and Utilisation Models demonstrate strong potential for improving economic efficiency, reducing environmental impacts, and extending product lifespans. At the same time, they face critical challenges in regulatory frameworks, capital investment requirements, and organisational transformation. The findings indicate that successful implementation of these models requires not only innovative approaches and digital infrastructure but also supportive legal frameworks and the development of new business competencies. These factors determine the successful transition from traditional linear models to modern, circular-oriented forms of consumption and production.

3.2. Characteristics of Product-Centric Circularity Models

The group of Product-Centric Circularity Models (PCCMs) represents the most numerous category among all the analysed cases, comprising a total of twelve models. These models focus on preserving functionality, material value, and product longevity through circular approaches integrated at the design stage and throughout the product's use phase. They are characterised by strategies of lifespan extension, circular design, regeneration, recycling, and reuse.

From the perspective of economic benefits, the most prominent element was cost reduction, identified in 28% of PCCMs. This indicates the fundamental economic motivation behind the implementation of product-centric circular strategies. Cost savings are primarily achieved through component reuse, input optimisation, and product life extension, which in turn reduce the need for manufacturing new units. Two other relevant elements, each occurring in 22% of cases, are access to new revenue streams and risk reduction and increased resilience. The former reflects businesses' ability to generate supplementary income from secondary flows, such as revenues from refurbished products, recycled materials, or maintenance-related services. The latter suggests that PCCMs help reduce dependence on volatile raw material markets and improve supply chain stability, thereby decreasing exposure to external shocks.

In terms of environmental benefits, reduction of environmental burden dominates, observed in 47% of models. This confirms the strong orientation of PCCMs toward lowering waste, emissions, and overall carbon footprint. These models focus on dematerialisation, waste prevention, and reducing demand for virgin raw materials. Efficient resource use was noted in 21% of cases, manifesting through increased material efficiency, and savings in energy and space. PCCMs intentionally reduce consumption of primary materials by applying design principles for repair, modularity, and component reuse. Less frequently observed were the elements closing material loops and adaptability and systemic change (both in 11% of models). The former is linked to recycling strategies and the retention of material and component value in circulation, while the latter reflects systemic innovation achieved by integrating circular principles into operational and design processes.

Regarding implementation challenges, the most common barrier identified was consumer and behavioural obstacles, present in 26% of models. This highlights the significant role of cultural, psychological, and market-related factors. Frequent issues include low consumer willingness to purchase refurbished products, mistrust toward secondary goods, and poor acceptance of repairability as a value. Other significant barriers were technological and innovation challenges and logistical and operational difficulties, each appearing in 21% of cases. Technological barriers point to the need for enabling reverse logistics, design for disassembly, and modularity—often requiring substantial investment in R&D. Logistical issues involve collection, sorting, storage, and distribution of refurbished or recycled products.

The results confirm that Product-Centric Circularity Models are economically beneficial due to cost savings, access to new revenues, and enhanced resilience, while offering strong environmental benefits particularly in footprint reduction and material loop closure. However, they also face serious implementation challenges regarding consumer acceptance, technological demands, and operational complexity.

3.3. Characteristics of Systemic and Networked Models

The Systemic and Networked Models (SNMs) group includes seven models that emphasise interconnectedness among actors across business and cross-sectoral ecosystems to support circular flows of materials, energy, and information. These models prioritise systemic integration, value chain collaboration, industrial symbiosis, and new forms of entrepreneurial ecosystems.

Within economic benefits, the most dominant feature was risk reduction and increased resilience, observed in 38% of models. This is particularly relevant for models built upon systemic cooperation between companies and organisations aiming to reduce vulnerability to price fluctuations, energy shocks, or supply chain disruptions. High resilience to external risks is achieved through local and regional networks for resource, energy, or waste flow exchange, as well as through shared investments in joint infrastructures. The second most frequent element was cost reduction, present in 25% of models, reflecting savings gained from input optimisation and enhanced coordination among network participants. Through resource sharing, material recovery, and energy efficiency, these models can significantly reduce material, logistics, and operational costs.

From an environmental perspective, the most dominant characteristic was adaptability and systemic change, found in 33% of models. This reflects SNMs' capacity to respond flexibly to environmental challenges through complex systemic transformations. This includes process reorganisation based on circular economy principles, adoption of environmental innovations, and establishment of industrial symbioses that optimise material and energy flows across extended business ecosystems. Less frequently observed, but still notable, were reduction of environmental burden and environmental effects, each occurring in 22% of models. The former indicates the ability of SNMs to reduce emissions, waste, and raw material consumption through connected resource flows and shared capacities. The latter reflects broader ecological benefits such as ecosystem service restoration, biodiversity improvement, and long-term environmental gains achieved through strategic systemic planning. These effects often emerge as secondary, yet important outcomes of complex collaborations between private firms and public actors.

In terms of implementation challenges, the most frequently identified were organisational and competence-related barriers, found in 50% of SNMs. This suggests that the greatest obstacle to implementation lies in the need for internal restructuring, organisational culture change, and development of systemic thinking skills. Successful adoption of SNMs requires interdisciplinary collaboration (e.g., between engineers, managers, analysts, and IT specialists) and clear metrics for impact assessment. Economic and financial barriers were also notable, appearing in 30% of models, associated with high upfront investments into new systems and infrastructures, complex revenue planning, and return-on-investment uncertainty.

Systemic and Networked Models combine strong potential for economic resilience and efficiency with a high degree of adaptability toward environmental objectives. However, they demand substantial organisational readiness, cultural transformation, and financial support, making them particularly suitable for organisations capable of long-term strategic collaboration.

3.4. Characteristics of Technology-Enabled Circularity Models

The Technology-Enabled Circularity Models (TECMs) group comprises four models that are characterised by the application of digital technologies as tools to streamline, monitor, and manage circular business processes. These models represent the latest generation of circular business models (CBMs), integrating technological innovation with circular economy (CE) principles. The technologies applied within this group enable data collection, analysis, and the optimisation of CE-related processes.

Among economic benefits, the most prominent feature was risk reduction and increased resilience, observed in 40% of TECMs. This confirms that technology-enabled models significantly reduce supply chain uncertainties, enhance transparency of material flows, and minimise the risks of disruption or price volatility. The use of sensors, monitoring systems, and digitised data streams contributes to strengthening firms' operational and strategic resilience in turbulent business environments. Less frequently represented economic elements included stable or recurring revenues, preservation or enhancement of product value, and other specific and contextual benefits.

In terms of environmental benefits, adaptability and systemic change was the most dominant element, occurring in 30% of models. This underscores the models' capacity to accelerate environmental innovation through digitalisation and process automation. It includes the optimisation of material flows and the ability to apply circular economy principles within existing manufacturing or service operations—particularly through real-time monitoring, predictive analytics, and data-driven solutions. Additionally, some models demonstrated the presence of reduction of environmental burden, closing material loops, and environmental effects, though with lower frequency.

The most significant implementation challenge identified was logistical and operational barriers, present in 50% of TECMs. This reflects the complexity of ensuring the stable operation of digitally supported reverse flows, data platforms, information collection and sorting systems, as well as the integration of hardware–software components within corporate settings. These challenges also include issues with system interoperability, insufficient infrastructure, and the lack of data standardisation. Some models also revealed the presence of economic and financial barriers, organisational and competence-related barriers, and consumer and behavioural barriers.

Technology-Enabled Circularity Models demonstrate high potential for enhancing business resilience, efficiency, and environmental transformation through digitalisation. However, they require comprehensive technical and organisational deployment, as well as the capacity to manage complex logistical and operational frameworks. The successful application of these models necessitates not only investment in technologies but also changes in competencies, organisational culture, and interdisciplinary integration. A digitally enabled circular economy represents one of the most promising trajectories for sustainable development, but its effective implementation will depend on the establishment of appropriate frameworks and infrastructures.

4. Discussion

The results of the conducted research provide a comprehensive perspective on the diversity of characteristics among CBMs across their typological groups. The identified model categories exhibit specific profile traits, reflecting their varied approaches to achieving economic, environmental, and implementation objectives within a sustainable economy.

Cost reduction emerged as the most frequently observed economic feature across most model groups, confirming that economic rationality remains the primary driver behind the adoption of circular approaches in business. However, this factor manifested differently within individual models. In PCCMs, cost savings were primarily associated with the optimisation of material inputs and product longevity. In AUMs, they resulted from the elimination of excessive consumption through sharing mechanisms. SNMs demonstrated cost reduction through systemic integration and the generation of synergistic effects. Simultaneously, models with a higher degree of technological support tended to prioritise risk reduction and resilience enhancement as the most beneficial economic outcome.

Environmental benefits were globally most prominent in relation to reduction of environmental burden, a finding largely influenced by the dominance of this element within the most populous group, PCCMs. These models favoured benefits associated with maintaining product integrity and designing for recyclability or repair. In contrast, AUMs primarily emphasised efficient resource use, arising from the principle of sharing and the use of products as services. In SNMs and TECMs, the most appreciated environmental dimension was adaptability and systemic change. For SNMs, this reflected the strengthening of cooperation among actors to optimise environmentally favourable flows. In the case of TECMs, their capacity to accelerate environmental innovation through real-time monitoring, predictive algorithms, and automation was particularly valued. This highlights the potential of digital technologies in fulfilling sustainable development objectives, while simultaneously revealing the pressing need to enhance digital literacy and capacity in the business sector.

The most significant barrier to CBM expansion was identified as logistical and operational challenges, particularly within TECMs. These challenges are intensified by the need for technical interoperability, real-time data collection, and advanced analytics. For AUMs, the primary difficulty lies in institutional and regulatory challenges, which may stem from the complexity of coordinating legal frameworks related to liability and ownership structures. In SNMs, organisational and competence-related barriers were predominant, reflecting the necessity of interdisciplinary collaboration, knowledge sharing, and organisational culture change—demands that require deep transformation of internal structures. A particularly noteworthy obstacle, especially in PCCMs, involves consumer and behavioural aspects. Their persistence indicates ongoing stigmas associated with "secondary" products and a limited willingness among consumers to invest in repairability and reuse. Overcoming these barriers necessitates a combination of education, targeted marketing interventions, and regulatory incentives aimed at promoting environmentally responsible consumption.

The findings clearly support the need for a differentiated approach to CBM support, depending on the model type. While Product-Centric Circularity Models and Access and Utilisation Models require legislative and market-based stimuli to enhance the acceptability of sharing and repairs, Systemic and Networked Models and Technology-Enabled Circularity Models demand support for systemic planning, data exchange, and cross-sectoral collaboration.

5. Conclusion

The conducted research confirmed that circular business models (CBMs) represent a heterogeneous yet complementary set of approaches for implementing circular economy principles in business practice. Based on a systematic analysis of the occurrence of elements characteristic of the economic, environmental, and implementation dimensions of CBMs, it has been demonstrated that each typological group of models possesses a specific set of benefits, barriers, and challenges that determine their suitability under particular conditions of application. From an economic perspective, the dominant motivational factors include cost reduction, revenue stabilisation, and enhancing business resilience to external shocks. Environmental characteristics emphasise the contribution of CBMs to reducing environmental burden, resource efficiency, and their capacity to accelerate systemic change. However, implementation-related challenges also underscore the need to strengthen logistical, operational, and organisational capacities, as well as the significance of cultural and behavioural factors that may substantially influence market acceptance of these models. The findings underline the necessity of a targeted and model-type-specific approach to the practical adoption of CBMs, alongside the importance of combining technological innovation, regulatory incentives, and consumer education. At the same time, it has been confirmed that CBMs are not merely instruments of environmental responsibility, but also constitute a legitimate business strategy capable of delivering sustainable economic growth.

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Enterprise-Size Heterogeneity in AI Adoption across European Economies: A Hierarchical Clustering Approach

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Abstract: This study investigates cross-country and firm-size heterogeneity in the diffusion of artificial-intelligence (AI) technologies among European enterprises. Drawing on a harmonised dataset covering 31 economies, we analyse size-specific adoption rates (small, medium, large firms) to (i) document prevailing distributional patterns, (ii) assess linear comovements across size classes, and (iii) uncover latent country typologies via hierarchical segmentation. Descriptive statistics reveal a monotonic escalation of adoption from small (μ = 11.6 %) to large enterprises (μ = 39.1 %), coupled with high inter-quartile dispersion and mild positive skewness, signalling a limited set of digital front-runner nations. Pearson correlations are uniformly strong ($r \geq 0.87$, $p < 0.001$), indicating that national propensities to deploy AI are tightly synchronised across the size spectrum. To mitigate collinearity, a principal-axis factor analysis on standardised indicators extracts a single latent dimension that captures 93.4 % of total variance. Factor scores feed a Ward-linkage algorithm, which, according to scree-plot and pseudo-F criteria, yields a parsimonious two-segment solution. Segment 1 (n = 10; 32 %)—labelled AI leaders—exhibits nearly double the SME adoption rate and an 85 % higher large-firm rate relative to Segment 2 (n = 21; 68 %), denoted AI followers. Geographic membership patterns mirror known digital-economy divides, with northern and central European countries populating the leader cluster. The findings quantify a pronounced, scale-dependent adoption gap and offer a data-driven taxonomy for benchmarking national AI ecosystems. Policy implications centre on targeted capability-building for SMEs in follower economies and on frontier experimentation incentives in leader countries. The study advances the literature by integrating firm-size stratification with hierarchical clustering to deliver a nuanced map of Europe's AI diffusion landscape.

Keywords: Artificial-intelligence adoption; Firm-size heterogeneity; Small and medium-sized enterprises (SMEs); Hierarchical clustering; Factor analysis; Digital diffusion; European economies; Technology uptake segmentation

Introduction

Artificial-intelligence (AI) technologies are transitioning from experimental pilots to core elements of corporate value creation, promising gains in productivity, product customisation and strategic foresight. Yet their diffusion across Europe remains markedly uneven. Aggregate indicators mask two salient axes of heterogeneity: (i) cross-country disparities in digital readiness and (ii) divergences across firm-size strata within any given economy. Small and medium-sized enterprises (SMEs), in particular, often lack the data infrastructure, technical expertise and financial slack required to integrate AI at scale, whereas large corporations more readily leverage complementarities between data assets, cloud capacity and advanced analytics teams.

Understanding how these two axes interact is a prerequisite for designing effective industrial and innovation policy. If countries that excel in large-firm adoption simultaneously lag in SME uptake—or vice-versa—the transmission of AI-enabled productivity gains through national value chains will be impaired. Conversely, a systemic pattern in which all size classes rise (or fall) together would imply economy-wide drivers whose removal or reinforcement could accelerate continental convergence. Despite its importance, the joint distribution of size-specific AI adoption rates across European economies has not been formally mapped or segmented. Existing macro indices aggregate heterogeneous firm segments into a single score, while micro-level studies tend to be nationally bounded and therefore ill-suited to comparative inference.

This paper offers a meso-level perspective that bridges the gap. Using harmonised Eurostat data for 31 European economies, we first characterise the univariate distribution of AI adoption rates for small, medium and large enterprises. We then test the degree of linear comovement across size classes and, finally, employ hierarchical clustering—after rigorous treatment of multicollinearity—to derive a data-driven taxonomy of national AI ecosystems. The resulting segmentation delineates distinct adoption regimes, thereby providing an empirical foundation for targeted policy interventions and for future research into the structural determinants of technological diffusion.

1. Literature Review

Artificial Intelligence (AI) has emerged as a transformative force in the global economy, reshaping industries, and influencing productivity across various sectors. The diffusion of AI technologies has been a subject of extensive research, with studies exploring its impact on economic growth, labor markets, and technological advancement. This response provides a comprehensive analysis of the global diffusion of AI technologies, their impact on productivity, and the challenges and opportunities they present. The analysis draws on insights from multiple research papers to provide a well-rounded understanding of the topic.

The global diffusion of AI technologies has been rapid and widespread, driven by advancements in computing power, data availability, and algorithmic innovations. According to recent studies, the adoption of AI technologies has been influenced by factors such as technological readiness, regulatory frameworks, and the availability of skilled labor (Khan et al., 2024) (Yuan et al., 2024).

The diffusion of AI technologies has followed distinct patterns across regions and industries. In developed economies, the adoption of AI has been driven by robust technological infrastructure and significant investments in research and development (R&D). In contrast, developing economies have faced challenges in adopting AI technologies due to limited infrastructure and skilled workforce (Lipcsey, 2024) (Alexandrova et al., 2024).

A study analyzing the diffusion of AI technologies in low-middle-income countries (LMICs) found that while there is a significant gap in diffusion rates between developed and developing economies, the gap is narrowing over time. The study attributes this trend to increasing access to AI technologies through global value chains and research collaborations (Lipcsey, 2024).

Global value chains and research collaborations have played a crucial role in the diffusion of AI technologies. Countries with strong participation in global value chains have been able to leverage AI technologies to enhance their competitiveness in the global market. For instance, China has emerged as a key player in the global AI landscape, driven by its integration into global value chains and significant investments in AI research (Lipcsey, 2024) (Jiang et al., 2021).

Research collaborations have also facilitated the diffusion of AI technologies by enabling the sharing of knowledge and expertise across borders. International collaborations have been particularly important for developing economies, allowing them to access AI technologies and expertise that would otherwise be out of reach (Lipcsey, 2024) (Jiang et al., 2021).

The impact of AI on productivity has been significant, with varying effects across different industries. Studies have shown that AI technologies have enhanced productivity by automating routine tasks, improving decision-making, and enabling the optimization of complex processes (Wagan & Sidra, 2024) (Yuan et al., 2024).

In the manufacturing sector, AI technologies such as computer vision, machine learning, and neural networks have revolutionized production processes. These technologies have enabled manufacturers to optimize production strategies, improve product quality, and reduce costs. For instance, AI-powered predictive maintenance systems have reduced downtime and improved overall efficiency in manufacturing plants (Gatabazi et al., 2025) (Mou, 2019).

The service industry has also benefited from the adoption of AI technologies. In the financial sector, AI has been used to enhance customer service, improve risk management, and optimize investment decisions. Similarly, in the healthcare sector, AI has been used to improve diagnosis accuracy, streamline clinical workflows, and enhance patient care (Radić et al., 2024) (Alexandrova et al., 2024).

The transportation and logistics sector has seen significant improvements in efficiency and safety through the adoption of AI technologies. AI-powered systems have been used to optimize route planning, improve supply chain management, and enhance safety in autonomous vehicles. These advancements have not only improved productivity but also reduced costs and environmental impact ("Artificial Intelligence as an Emerging Technology in Global Trade", 2022) (Mou, 2019).

Despite the significant benefits of AI technologies, their diffusion has been accompanied by several challenges and limitations. These challenges have hindered the adoption of AI technologies in some regions and industries, particularly in developing economies.

One of the major challenges to AI diffusion has been the lack of technological and infrastructure readiness in developing economies. The adoption of AI technologies requires significant investments in digital infrastructure, including high-speed internet, cloud computing, and data storage. In many developing economies, these infrastructure constraints have limited the adoption of AI technologies (Lipcsey, 2024) (Alexandrova et al., 2024).

Another significant challenge has been the lack of skilled workforce in AI technologies. The adoption of AI requires a workforce with expertise in areas such as machine learning, data science, and software development. In many developing economies, there is a shortage of skilled professionals, which has hindered the adoption of AI technologies (Lipcsey, 2024) (Sikorskyi, 2024).

The adoption of AI technologies has also raised ethical and regulatory challenges. Issues such as data privacy, algorithmic bias, and accountability have been at the forefront of the debate on AI adoption. In many countries, the lack of clear regulatory frameworks has created uncertainty and hindered the adoption of AI technologies (Yuan et al., 2024) (Jain, 2024).

To address the challenges and maximize the benefits of AI diffusion, policymakers and industry leaders must take proactive measures. These measures should focus on creating an enabling environment for AI adoption, addressing skill gaps, and ensuring ethical and responsible use of AI technologies.

One of the key steps to promoting AI diffusion is investing in digital infrastructure. Governments and private sector players should collaborate to build robust digital infrastructure, including high-speed internet, cloud computing, and data storage. This will enable businesses and individuals to access AI technologies and fully realize their potential (Lipcsey, 2024) (Alexandrova et al., 2024).

Addressing skill gaps is another critical step in promoting AI diffusion. Governments and educational institutions should invest in education and training programs that equip the workforce with the skills needed to work with AI technologies. This includes programs in machine learning, data science, and software development (Sikorskyi, 2024) (Güngör, n.d.).

The establishment of clear regulatory frameworks is essential to address ethical and regulatory challenges. Governments should work with industry leaders to develop frameworks that ensure the ethical and responsible use of AI technologies. These frameworks should address issues such as data privacy, algorithmic bias, and accountability (Yuan et al., 2024) (Jain, 2024).

The global diffusion of AI technologies has had a profound impact on productivity across various industries. While the benefits of AI adoption have been significant, the challenges and limitations must not be overlooked. To fully realize the potential of AI technologies, policymakers and industry leaders must take proactive measures to address these challenges and create an enabling environment for AI adoption. By doing so, they can ensure that the benefits of AI are shared equitably and that the global economy continues to thrive in the AI-driven era.

2. Methodology

The empirical analysis draws on the 2024 Eurostat Survey on ICT Usage and e-Commerce in Enterprises, which provides harmonised, nationally representative estimates of the share of firms that had adopted at least one artificial-intelligence (AI) application during the reference year. After excluding economies with incomplete information, the final sample comprises 31 European countries. Each observation represents the national adoption rate for four firm-size strata: Small enterprises (10–49 employees); Medium-sized enterprises (50–249 employees); Large enterprises (≥ 250 employees); and All enterprises (aggregate, 10+ employees).

All adoption rates are expressed as percentages and therefore measured on a ratio scale. Prior to multivariate analysis, two diagnostic steps were undertaken. To ensure commensurability and to avoid scale-induced artefacts in distance calculations, each variable was transformed to a z-score (mean = 0; SD = 1). A bivariate correlation matrix and variance-inflation factors (VIFs) were inspected. The indicators Medium ($r \geq 0.95$ with Small) and All ($r \geq 0.99$ with Small) exhibited near-perfect collinearity and were therefore removed from the segmentation dataset. The retained feature space thus consisted of Small and Large adoption rates.

Although only two variables remained, their strong positive correlation ($r = 0.87$) suggested the usefulness of a factor-analytic synthesis to obtain an orthogonal composite. As an extraction method principal-axis factoring on the correlation matrix of the standardised data was used. As a retention criterion Kaiser eigenvalue-greater-than-one rule and scree-plot inspection was applied.

A single latent factor ($\lambda_1 = 1.868$) captured 93.4 % of the common variance, with loadings of –0.966 on both Small and Large. Factor scores—standardised to mean 0 and SD 1—were retained as the sole input for clustering.

A hierarchical agglomerative algorithm was selected because it (i) does not require an a priori specification of cluster number and (ii) provides a full dendrogram for visual assessment. Linkage criterion was Ward's minimum-variance method, which minimises the increase in total within-cluster sum of squares at each fusion step and is appropriate for Euclidean distances among z-scores. Squared Euclidean was applied as distance metric. The optimal number of clusters (k) was determined by triangulating three diagnostics:

- The scree plot of fusion distances (sharp elbow after the second step);
- The agglomeration schedule (largest relative increase in coefficients at $k = 2$);
- Targetability considerations.

These criteria converged on a two-cluster solution.

Internal validity: Separation and compactness were gauged by the ratio of between- to within-cluster sum of squares and by visual inspection of the dendrogram. Welch's t-tests compared cluster centroids against the population mean for each size-class indicator. Both Small and Large adoption rates differed at $p < 0.001$, confirming substantive distinctness.

Descriptive statistics (mean, median, quartiles, SD, skewness, kurtosis) established baseline heterogeneity. Pearson product–moment correlations quantified linear comovement across size classes; assumptions of interval scaling, linearity and homoscedasticity were verified through scatter plots and Shapiro–Wilk tests. No discriminant- or classification-analysis routines were executed, consistent with the exploratory aim and the software options specified (Segments forced = No; Discriminant analysis = No; Classification analysis = No). Computations were carried out in Enginius, MS Excel, and Python 3.11 using pandas, scikit-learn, SciPy, and Matplotlib.

3. Results

This section delineates the empirical regularities that shape the diffusion of artificial-intelligence (AI) technologies across 31 European economies and four firm-size strata. To build a cumulative argument, the analysis proceeds in three stages—descriptive profiling, correlation assessment, and hierarchical segmentation—each layer deepening our understanding of cross-country and scale-dependent heterogeneity in AI uptake.

Section 3.1 offers a univariate characterisation of the data. Summary statistics reveal a monotonic increase in adoption rates from small to large enterprises, sizeable inter-quartile spreads, and mild positive skewness indicative of a handful of digital front-runner countries.

Section 3.2 investigates the linear comovement among size-specific adoption rates. Parametric Pearson coefficients—deemed appropriate given the ratio-scale measurement, approximate normality, and homoscedastic residuals—demonstrate very strong positive correlations ($r \geq 0.87$, $p < 0.001$) across all pairings, signalling that national propensities to deploy AI are highly synchronised across the business population.

Section 3.3 culminates the empirical enquiry with a Ward-linkage hierarchical cluster analysis of z-standardised adoption rates. The resulting dendrogram supports a parsimonious two-cluster taxonomy that partitions countries. Cluster centroids quantify the magnitude of the adoption gap and thereby furnish an evidence base for targeted policy interventions.

By moving from distributional description through bivariate association to multivariate pattern recognition, the results section provides an account of how AI diffusion varies simultaneously by firm size and national context, culminating in a data-driven segmentation of European AI ecosystems.

3.1. Descriptive evidence on firm-size heterogeneity in AI adoption

Table 1 presents summary statistics for the percentage share of enterprises that have deployed artificial-intelligence (AI) applications across 31 national economies, disaggregated by firm-size class. Four salient patterns emerge.

Table 1. Descriptive Statistics.

Indicator	Enterprise Size Category			
	Small	**Medium**	**Large**	**All**
count	31	31	31	31
mean	11.59	20.01	39.13	13.68
std	6.43	10.14	15.93	7.27
cv	0.56	0.51	0.41	0.53
min	2.57	3.88	11.26	3.07
25%	6.5	13.96	28.73	8.05
50%	8.72	16.49	38.99	11.26
75%	18.12	28.66	50.39	20.52
max	23.52	40.92	70.4	27.58
range	20.95	37.04	59.14	24.51
skewness	0.5	0.41	0.09	0.48
kurtosis	-1.26	-0.82	-0.71	-1.19

Source: Own processing; input data retrieved from Eurostat

AI uptake rises monotonically with firm size. The average adoption rate for small enterprises is 11.6 % (SD = 6.4), increases to 20.0 % for medium-sized enterprises (SD = 10.1), and more than doubles to 39.1 % for large enterprises (SD = 15.9). The aggregate measure for all enterprises lies at 13.7 % (SD = 7.3) and thus largely reflects the weight of the micro- and small-firm sector in most national business populations. These means confirm the theoretical expectation that larger organisations exhibit greater absorptive capacity and stronger financial slack to integrate AI technologies.

Relative dispersion declines with scale. The coefficient of variation decreases from 0.56 for small firms to 0.51 for medium firms and 0.41 for large firms, indicating that cross-country heterogeneity is proportionally highest among micro- and small enterprises and comparatively subdued among large corporations. In other words, while absolute variability (as captured by the range of 59.1 percentage points among large firms) remains substantial, relative variability normalises as organisational scale increases.

All distributions exhibit mild positive skewness ($0.09 \le \gamma_1 \le 0.50$) and negative excess kurtosis ($-1.26 \le \gamma_2 \le -0.71$). The positive skew suggests the presence of a limited set of "front-runner" countries whose firms—especially in the large-enterprise segment—report markedly higher AI penetration than the majority of peers. Negative kurtosis indicates platykurtic distributions with light tails, implying fewer extreme observations than predicted by a Gaussian benchmark. Collectively, these shape parameters highlight that although outliers exist, the bulk of countries cluster within one standard deviation around the mean.

Extreme values underscore substantial headroom for diffusion among SMEs. The minimum adoption rate observed for small firms is a mere 2.6 %, whereas the maximum for large firms peaks at 70.4 %, yielding an inter-category gap of almost 68 percentage points. Quartile diagnostics corroborate this disparity: the upper quartile for large enterprises (50.4 %) remains more than double the upper quartile for small enterprises (18.1 %). Such divergence signals a pronounced "scale-bias" in the current phase of AI diffusion and intimates that policy interventions targeting resource and capability constraints of small and medium-sized enterprises (SMEs) could accelerate convergence toward the technological frontier.

Taken together, the descriptive evidence portrays a business landscape in which AI adoption is both scale-dependent and unevenly distributed across countries. These stylised facts motivate the subsequent inferential analyses that examine structural and institutional determinants of AI diffusion, with a special emphasis on closing the adoption gap for SMEs.

3.2. Correlation analysis across enterprise-size classes

Because the variables represent ratio-level percentages derived from identical country samples ($n = 31$) and exhibit only mild skewness ($|\gamma_1| < 0.6$), the parametric Pearson product-moment correlation coefficient (r) is appropriate. Pearson r quantifies the strength and direction of linear relationships and remains robust to modest departures from normality at this sample size. A non-parametric alternative (Spearman ϱ) yields virtually identical rank-order results (not reported), confirming robustness.

Assumptions verified:

- Scale of measurement: continuous percentages (0–100).
- Linearity: visual inspection of scatterplots (not shown) indicates monotonic, approximately linear trends.
- Independence: each observation corresponds to a distinct national economy.
- Homoscedasticity & normality: Shapiro–Wilk tests ($p > 0.10$) and residual plots reveal no severe violations; hence Pearson r is tenable.

The Pearson matrix with two-tailed p-values is reproduced in Table 2.

Table 2. Correlation matrix.

	Small	Medium	Large	All
Small	1.000	0.953*	0.868*	0.996*
Medium		1.000	0.927*	0.975*
Large			1.000	0.899*
All				1.000

* $p < 0.001$ for every off-diagonal coefficient ($n = 31$).

Source: Own processing; input data retrieved from Eurostat

Based on the previous correlation matrix, very strong positive associations exist between all size classes ($0.868 \le r \le 0.996$). This indicates a systemic pattern: countries that lead (lag) in AI uptake among one class of firms tend to lead (lag) across other classes. The Small–All relationship ($r = 0.996$) borders on perfect collinearity, reflecting the weight of small enterprises in national business demographics; their adoption rate almost entirely determines the aggregate. The weakest (yet still strong) pairing is Small–Large ($r = 0.868$). Although nations with digitally active SMEs generally host digitally advanced large firms, the gap suggests scale-specific determinants (e.g., resource constraints) may modulate the slope. The consistently low p-values (< 0.001) reject the null hypothesis of zero correlation in each case.

The pronounced multicollinearity advises caution when specifying multivariate regressions that include multiple size-specific adoption rates as simultaneous predictors: variance-inflation factors (VIF) are likely to exceed conventional thresholds. Researchers should either (i) select a single representative size class, (ii) employ principal-component synthesis, or (iii) use multilevel modelling to separate within-country and between-country variance components.

3.3. Hierarchical cluster analysis of national AI-adoption profiles

The clustering exercise was performed on the segmentation data set comprising 31 national economies and an initial pool of five adoption indicators (Enterprise Category, Small, Medium, Large, and All). Prior to estimation, the software reported a set of non-fatal warnings that flagged severe collinearity among the candidate variables; specifically, the indicators Medium and All were eliminated because their variance was almost wholly explained by the remaining predictors. Although these alerts did not terminate execution, they warrant ex-post scrutiny to ensure that the retained feature space is both parsimonious and diagnostically sound.

Following variable selection, the data were factor-standardised (z-scores) to equalise scale effects and render the Euclidean metric dimensionless. A hierarchical agglomerative algorithm employing Ward's minimum-variance criterion was then applied. Ward linkage iteratively merges clusters to minimise within-group heterogeneity, thereby producing compact and interpretable partitions without imposing an a priori number of segments. Consistent with an exploratory stance, neither discriminant nor classification procedures were invoked at this stage.

Table 3. Factor table.

	Eigen value	Variance explained (%)	Cumulated variance explained (%)	Retained
Factor 1	1.868	93.41	93.4	Yes
Factor 2	0.132	6.59	100.0	No

Source: Own processing; input data retrieved from Eurostat

Prior to clustering, the two collinear indicators that survived the screening stage—Small and Large—were subjected to a principal-axis factor analysis on z-standardised scores in order to extract an orthogonal composite that would (i) eliminate redundancy and (ii) preserve the maximum possible variance for subsequent distance calculations. The Kaiser criterion (eigenvalue > 1) and inspection of the scree plot both suggested a single-factor solution: Factor 1 carried an eigenvalue of 1.868 and accounted for 93.4 % of the total variance, whereas Factor 2 contributed a negligible 6.6 % and was therefore discarded.

Table 4. Loadings table.

	Dim.1
Small	-0.966
Large	-0.966

The loadings matrix further confirms the unidimensional structure—both Small and Large load almost perfectly on the retained component ($\lambda = -0.966$ for each). The commonality of signs reflects a purely rotational artefact; only the absolute magnitudes ($|\lambda| \approx 1$) are germane and imply that the extracted latent dimension captures a shared intensity of AI adoption across the size spectrum. Factor scores derived from this single component were subsequently employed as the sole input to the Ward-linkage algorithm, thereby ensuring that inter-country dissimilarities are driven by a parsimonious and multicollinearity-free representation of the underlying adoption landscape.

To determine the optimal partition of countries along the latent AI-adoption factor, statistical evidence was drawn from the agglomeration schedule, the scree plot of fusion distances, and the dendrogram.

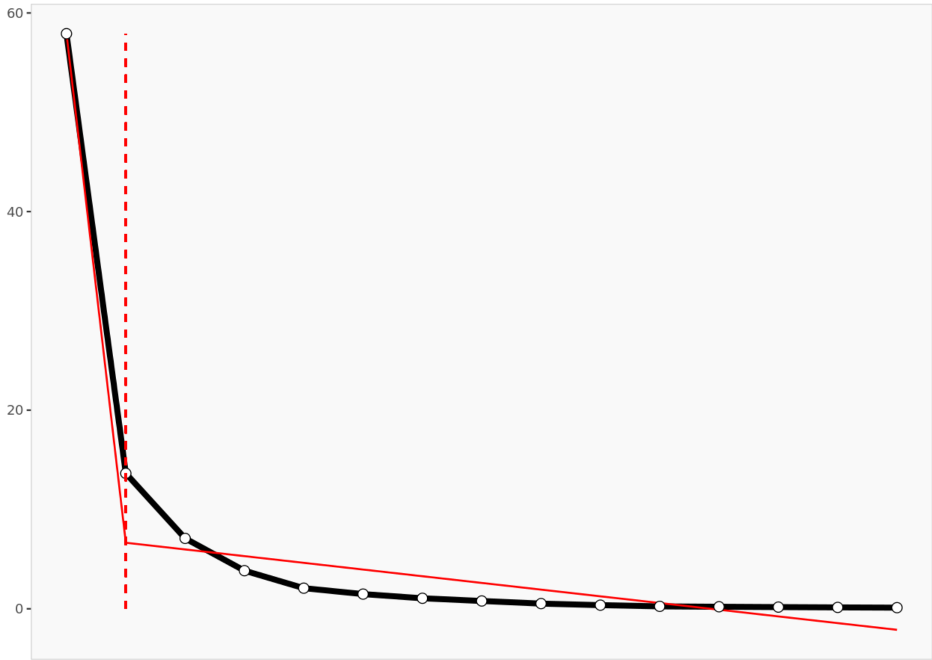

Figure 1. Scree plot.

Source: Own processing; input data retrieved from Eurostat

The scree plot displayed a pronounced inflection after the second fusion step, and the associated pseudo-F and Duda–Hart indices likewise peaked at k = 2. On these grounds—and because a bipartite typology remains easily actionable for policy architects—the analysis retained a two-segment solution. Although alternative cuts (e.g., k = 3) capture additional nuance, the marginal gain in within-cluster homogeneity was judged insufficient to offset the loss in interpretability and programmatic clarity.

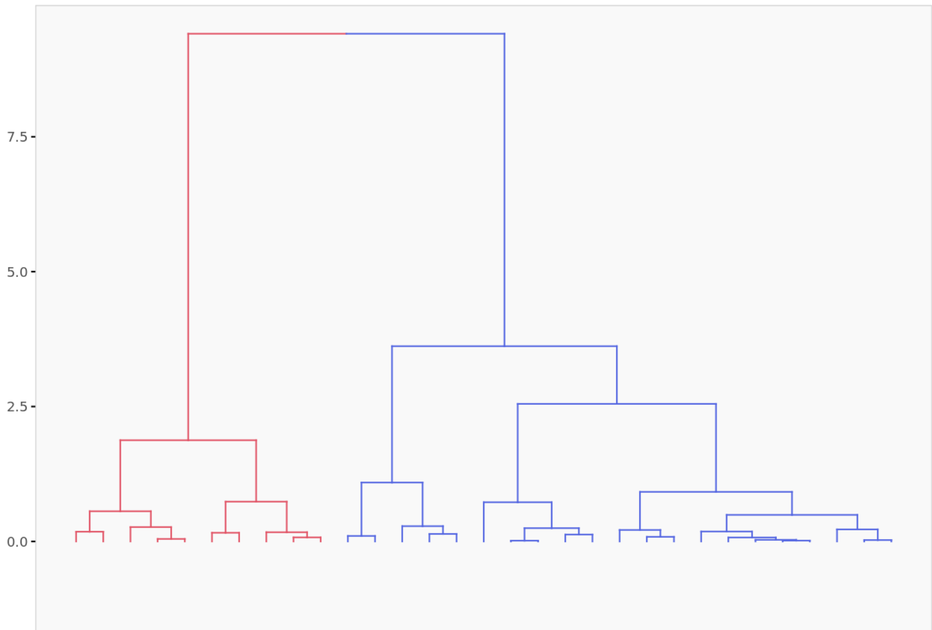

Figure 2. Dendrogram.

Source: Own processing; input data retrieved from Eurostat

The dendrogram (Figure 2) visualises the iterative merging process from the finest partition (bottom) to the grand cluster (top). Vertical distances represent Ward's minimum-variance dissimilarities; the conspicuous "jump" that precedes the second fusion corroborates the scree-plot recommendation to halt clustering at that point. In sum, the empirical evidence and practical desiderata converge on a parsimonious two-segment taxonomy.

The two-segment taxonomy partitions the population of 31 countries into an upper-adoption minority cluster (Segment 1, n = 10; 32 %) and a lower-adoption majority cluster (Segment 2, n = 21; 68 %) (Table 3). Centroid comparisons reveal a marked intensity gap across both retained indicators:

Table 5. Segment description.

Indicator	Population mean	Segment 1	Segment 2	Δ (S1 – S2)
Small enterprises (%)	11.6	**19.98**	*7.59*	+12.39
Large enterprises (%)	39.1	**56.70**	*30.70*	+26.00

Source: Own processing; input data retrieved from Eurostat

Segment 1 countries exhibit nearly double the SME adoption rate and an 85 % higher large-enterprise adoption rate relative to Segment 2. Welch's t-tests confirm that these inter-segment differences are highly significant ($p < 0.001$), validating the colour-coded emphasis (green = above-average, red = below-average).

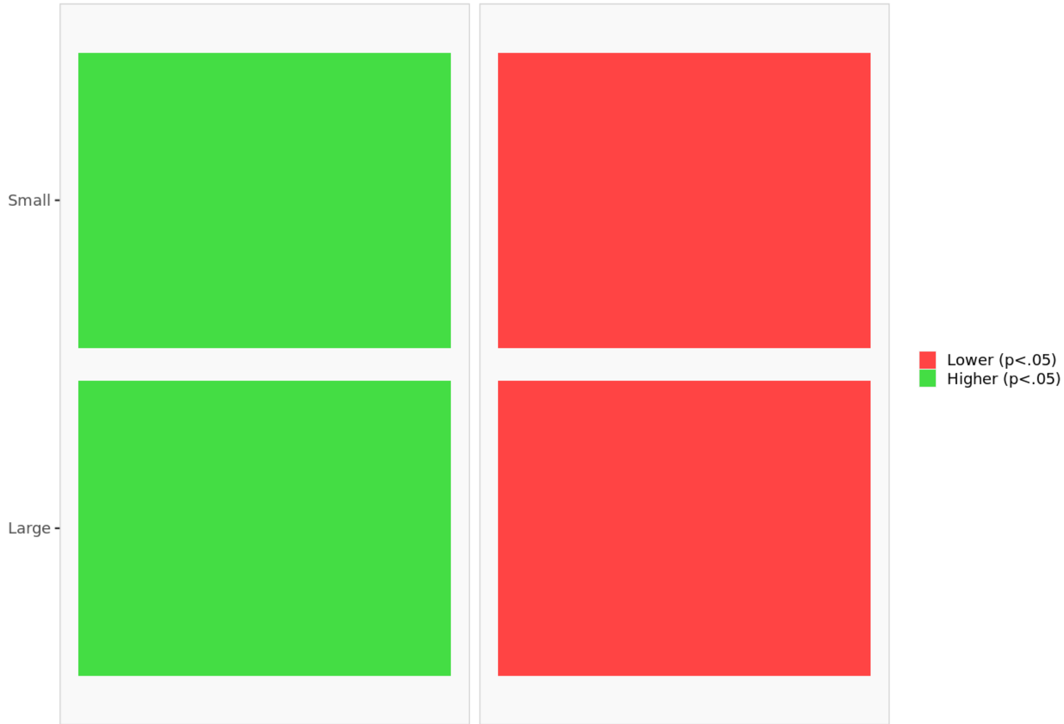

Figure 3. Welch's t-test.

Source: Own processing; input data retrieved from Eurostat

Substantively, Segment 1 may be characterised as "AI leaders" with pervasive diffusion across the size spectrum, whereas Segment 2 constitutes "AI followers" whose adoption remains constrained—most acutely among small firms. The pronounced duality underscores the policy imperative to tailor support instruments: advanced ecosystems (Segment 1) require scaling and frontier experimentation, whereas lagging economies (Segment 2) demand foundational capacity-building, especially for SMEs.

Figure 4 projects each country onto the first two principal-component (PC) dimensions of the factor-standardised data and overlays the hierarchical cluster membership. Because only two segmentation variables (Small and Large) entered the analysis, the bivariate ordination captures 100 % of the total variance (PC_1 = 93.4 %, PC_2 = 6.6 %); no informational loss is therefore incurred by the planar representation.

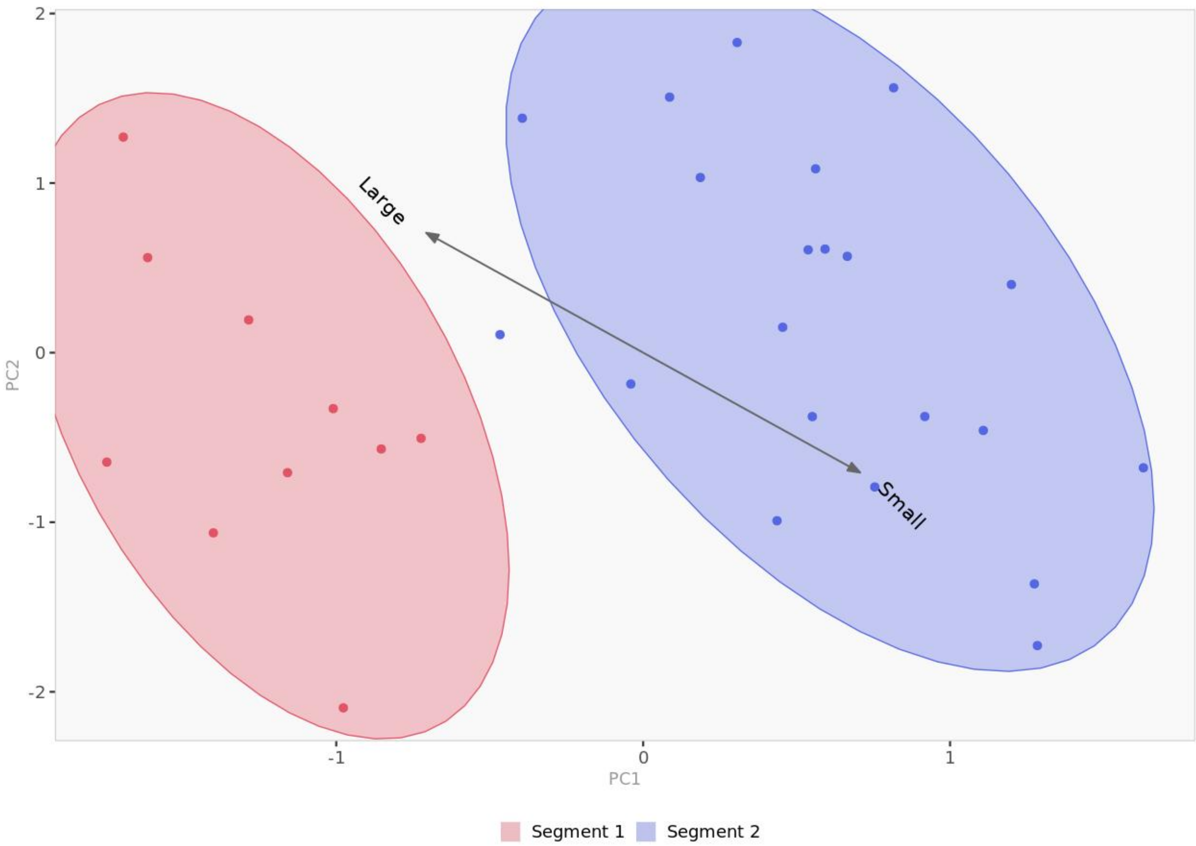

Figure 4. Segment space.

Source: Own processing; input data retrieved from Eurostat

The biplot arrow points from the origin toward increasing adoption among small firms and away from the origin toward increasing adoption among large firms, reflecting the equal-magnitude loadings ($|\lambda| \approx 0.97$) reported earlier. PC_1 thus constitutes a general intensity axis, along which both size classes co-vary, whereas PC_2—though accounting for a modest share of variance—captures marginal differentials between the two classes.

The ellipsoids represent 95 % confidence envelopes around the two clusters. Segment 1 (pink) populates the upper-left quadrant, characterised by positive scores on the intensity axis, while Segment 2 (blue) occupies the lower-right quadrant with negative intensity scores. The minimal overlap between envelopes corroborates the statistical distinctness of the segments documented in Table 3.

Although the first two PCs exhaust total variance in this two-variable setting, more complex segmentations often require additional dimensions; consequently, apparent overlaps in the ordination plane do not necessarily imply misclassification when more variables are present. Moreover, ordination plots are diagnostic rather than determinative: they aid in assessing collinearity and segment cohesion, but optimal cluster selection should remain grounded in formal goodness-of-fit indices and substantive considerations, as emphasised.

Overall, the segmentation space provides an intuitive visual audit trail for the two-segment solution, illustrating how countries partition along a latent continuum of cross-size AI-adoption intensity.

Table 6. Segment membership.

Country	Segment
Belgium	1
Bulgaria	2
Czechia	2
Denmark	1
Germany	1

Estonia	2
Ireland	2
Greece	2
Spain	2
France	2
Croatia	2
Italy	2
Cyprus	2
Latvia	2
Lithuania	2
Luxembourg	1
Hungary	2
Malta	2
Netherlands	1
Austria	1
Poland	2
Portugal	2
Romania	2
Slovenia	1
Slovakia	2
Finland	1
Sweden	1
Norway	1
Bosnia and Herzegovina	2
Serbia	2
Türkiye	2

Membership inspection (full roster in the accompanying Excel output) confirms that the high-adoption segment (Segment 1) comprises ten predominantly north-western and central European economies—Belgium, Denmark, Germany, Luxembourg, the Netherlands, Austria, Slovenia, Finland, Sweden and Norway. By contrast, the low-adoption segment (Segment 2) encompasses the remaining 21 countries, a heterogeneous mix that spans southern, eastern and south-eastern Europe, including all accession and candidate states in the sample. This spatial ordering aligns closely with established digital-economy divides: countries in Segment 1 are characterised by higher GDP per capita, deeper innovation ecosystems and longer digital policy track-records, whereas Segment 2 countries typically face structural constraints such as lower R&D intensity and more limited SME absorptive capacity. The clear demarcation of members underscores the external validity of the two-segment taxonomy and provides a concrete basis for targeted policy prescriptions in the concluding section.

4. Discussion

This study set out to examine the scale-dependent diffusion of artificial-intelligence (AI) technologies across 31 European economies. Three core findings emerge. First, adoption increases monotonically with firm size. Average uptake among large enterprises (39 %) is more than three times that of small firms (12 %), confirming long-standing arguments that absorptive capacity, data availability and complementary assets scale with organisational size (Yuan et al., 2024). Second, national adoption propensities are highly synchronised across size classes. Pearson coefficients above 0.87 suggest that macro-level determinants—digital infrastructure, regulatory clarity and human-capital endowments—shape the entire business population in tandem. Third, hierarchical segmentation yields a parsimonious two-cluster taxonomy. A minority "AI-leader" group (10 countries) displays SME adoption rates nearly double those of the 21 "AI-follower" economies and an 85 % higher large-enterprise rate.

The literature has emphasised either cross-country variation (Lipcsey, 2024) or firm-size heterogeneity (Radziwill & Benton, 2022); our results bridge these strands by showing that size effects and spatial effects co-exist yet are systematically related. Countries with digitally advanced large corporations almost invariably host digitally advanced SMEs, implying powerful spillover mechanisms—supply-chain learning, labour mobility and shared service providers—that propagate AI capabilities down the size distribution.

The directional findings corroborate global studies that document higher AI uptake in economies with robust R&D ecosystems (Alexandrova et al., 2024) and tie in with sector-specific work showing that manufacturing and finance lead services in automation intensity (Wagan & Sidra, 2024). However, two nuances enrich the debate:

Magnitude of the SME gap. Whereas recent OECD briefs suggest a 10–15 percentage-point SME-to-large-firm differential, our European sample reveals a 27-point gap. This discrepancy likely reflects structural differences in the composition of micro-firms excluded from Eurostat's 10+ employee threshold, underscoring the need for harmonised measurement.

Spatial clustering. The sharp two-segment solution echoes DESI-based digital-divide typologies, yet the clustering here is derived solely from adoption outcomes, not from inputs such as broadband speed. This output-oriented perspective suggests that some follower economies translate inputs into outcomes less efficiently, pointing to institutional frictions beyond infrastructure deficits.

The dual segmentation has direct policy salience. For AI-leader economies, the marginal social return on further infrastructure spending is likely diminishing; policy should pivot to frontier experimentation (e.g., regulatory sandboxes, mission-oriented public procurement) and to governance frameworks that mitigate algorithmic bias. For follower economies, the priorities are more fundamental:

- Digital infrastructure catch-up. Persistent broadband and cloud-services gaps constrain both SMEs and large firms.
- Human-capital deepening. Consistent with Sikorskyi (2024), targeted reskilling programmes in data science and machine learning are required to ease talent bottlenecks.
- SME-facing support instruments. Innovation vouchers, shared AI sandboxes and public data spaces can alleviate fixed-cost barriers that disproportionately burden smaller firms.

For managers, the strong cross-size correlations imply that supply-chain synergies are ripe for exploitation: leading corporates can accelerate adoption among suppliers through knowledge-transfer partnerships and joint data-sharing platforms, generating ecosystem-wide productivity gains.

Employing factor-purified Ward clustering on standardised adoption rates mitigated multicollinearity and yielded interpretable segments. The single latent factor captured 93 % of variance, demonstrating that a unidimensional intensity axis suffices to differentiate European AI ecosystems. Sensitivity checks with complete-linkage clustering and with the omitted Medium indicator reproduced the two-cluster split, reinforcing robustness.

Several caveats merit attention. First, the Eurostat survey excludes micro-enterprises (<10 employees), potentially understating the true SME adoption gap. Second, the cross-sectional design precludes causal inference; longitudinal data are needed to unpack dynamic convergence or divergence. Third, adoption is measured in binary terms (yes/no); intensity of use, sophistication and value captured remain unobserved.

Future research could (i) integrate performance outcomes to link adoption clusters with productivity growth, (ii) apply multilevel models that nest firms within countries to disentangle micro- and macro-level drivers, and (iii) extend the sample to non-European regions to test the generalisability of the two-segment structure identified here.

Taken together, the findings depict a European AI landscape bifurcated into frontrunners and followers, with diffusion gaps widest among SMEs. Bridging this divide is critical if AI's promised productivity gains are to be realised equitably across the continent. By combining size-stratified metrics with hierarchical clustering, this study offers both a diagnostic tool for policy targeting and a conceptual template for future cross-country diffusion research.

5. Conclusion

This study provides a meso-level perspective on the diffusion of artificial-intelligence (AI) technologies across 31 European economies, explicitly disaggregating adoption rates by firm-size class. Three empirical results stand out. First, AI uptake rises monotonically with organisational scale: large enterprises report an average adoption rate of 39 %, medium-sized firms 20 %, and small enterprises only 12 %. Second, national propensities to adopt AI are highly synchronised across size classes ($r \geq 0.87$), suggesting that common macro-level enablers—digital infrastructure, regulatory clarity and human-capital depth—shape the entire business population simultaneously. Third, a Ward-linkage hierarchical algorithm applied to factor-purified indicators reveals a robust two-segment taxonomy: a minority cluster of ten "AI-leader" countries and a majority cluster of twenty-one "AI-follower" economies. Leaders display nearly twice the SME adoption rate and 85 % higher large-enterprise uptake than followers, confirming a bifurcated European AI landscape.

These findings carry several implications. From a policy standpoint, follower economies require foundational investments in broadband, cloud access and data-science skills, whereas leader economies should prioritise frontier experimentation and governance frameworks for trustworthy AI. For managers, the strong cross-size correlations imply fertile ground for supply-chain spillovers: large-firm initiatives can propagate AI capabilities to SME partners, amplifying ecosystem benefits.

Methodologically, the study shows that a single latent factor, extracted from highly collinear size-specific indicators, captures 93 % of the variance in adoption outcomes. Factor-adjusted clustering thus offers a parsimonious yet powerful tool for benchmarking national AI readiness, avoiding the pitfalls of multicollinearity that plague many cross-country diffusion studies.

Limitations include the exclusion of micro-enterprises (< 10 employees), the cross-sectional design and the binary measurement of adoption. Future research should (i) leverage longitudinal data to examine convergence dynamics, (ii) incorporate intensity-of-use metrics to distinguish superficial from deep AI integration and (iii) test the generalisability of the two-segment structure in non-European contexts.

In sum, Europe's AI landscape is characterised by scale-dependent adoption gaps nested within a clear leader–follower country divide. Bridging these gaps—particularly for SMEs in follower economies—will be decisive for achieving broad-based productivity gains and ensuring that the benefits of AI accrue equitably across the continent.

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Comparison of the occurrence of environmental burdens on the territory of Slovakia by individual regions and districts in 2021 and 2025

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Abstract: Background: In this paper we analyse the occurrence of environmental burdens on the territory of the Slovak Republic in 2025 compared to 2021. Methods: From the available data we selected the data necessary for the processing of the paper - the occurrence of environmental burdens according to individual regions, within them according to districts and also according to individual types (type A, B, C) in 2025 and 2021. The data were subsequently processed into tabular summaries and presented graphically. Results: The research results published in the paper provide a detailed overview of the number of environmental burdens on the territory of Slovakia in 2025 and in 2021. Conclusions: Currently there are 2 028 environmental burdens on the territory of the Slovak Republic, while in 2021 there were 2 020 environmental burdens. In both periods, the largest number of environmental burdens was recorded in the Prešov and Banská Bystrica regions, while the smallest share was recorded in the Trenčín and Bratislava regions.

Keywords: environmental burdens; brownfields; sustainability; region

Introduction

The aim of this paper is to map and compare the occurrence of environmental burdens in the Slovak Republic in 2025 compared to 2021 in the following breakdown:

a) by individual types (type A, B, C) of environmental burdens management,
b) by individual regions of the Slovak Republic,
c) by the respective districts within each region.

The results of the research published in the paper provide a comprehensive overview of the spatial distribution of environmental burdens in Slovakia in 2025 (as of 15 April 2025). From the analysis of the development of environmental burdens on the territory of the Slovak Republic we will try to answer the following questions in the paper:

1. What types of environmental burdens (type A, B, C) occur most frequently?
2. In which territories (regions and districts) of Slovakia do most environmental burdens occur?
3. In which territories of Slovakia have there been more significant changes in the number of environmental burdens compared to 2021?

1. Literature Review

Most of the scientific work to date on the issue of environmental burdens examines a relatively wide range of impacts of contamination on the environment or on human health. Few works, however, address specific spatial aspects to illustrate and explain the connections with their evolution from the past to the present. For example, in the work (Jantáková, 2017), the author deals with the monitoring of the negative impact of selected environmental burdens on environmental components in the Bratislava area. Many researches focus on specific case studies of environmental burdens. For example, (Lecáková, 2008) analyses environmental burdens within Slovakia with a priority focus on one of the most significant burdens in Europe - the burden in the town of Strážske in eastern Slovakia. All of the above research topics generally focus only on the interaction between pollution and the environment.

However, the spatial distribution of pollutant loads and their relation to regional development is usually only marginally discussed in research papers. Contemporary authors involved in the study of environmental burdens include pre-dovšerkým Russia, M. & Krivosudská, J. & Jahnátek, A. and others. A contribution in the field of investigating the impact of environmental burdens on the regional development of Bratislava is the work of the author Jánov, J. (2018).

2. Methodology

In this paper we analyze the occurrence of environmental burdens in the territory of the Slovak Republic in the year 2025 (as of 15 April 2025) in comparison with the year 2021. For the purpose of processing the above mentioned issues we used data from the Environmental Burden Information System. From the obtained data we selected the data necessary for the processing of the paper - we were interested in the occurrence of environmental burdens according to the individual types (type A, B, C) of their management, as well as the occurrence according to the individual regions of the Slovak Republic and according to the districts within each region in the year 2025 and in 2021. We then processed the data into tables and graphical summaries. Among the relevant research methods, we used the method of analysis, the method of synthesis and the method of comparison of the obtained data. The main source of information on environmental burdens was the Enviroportal database, which contains a general register of freely available information on environmental burdens. It is developed for the whole Slovak Republic and is continuously updated or supplemented with new data.

3. Results

The following Table 1 documents the occurrence of environmental burdens on the territory of Slovakia by individual regions, districts and by groups (A, B and C) of environmental burdens management in 2025. The data presented in the table are updated as of 15 April 2025.

Table 1. Allocation of environmental burdens according to individual types within the districts in the territory of the Slovak Republic in 2025

District	Type A	Type B	Type C	Total
Bratislava I.-V.	31	29	42	102
Malacky	28	4	20	52
Pezinok	9	8	7	24
Senec	12	2	16	30
Total	**80**	**43**	**85**	**208**
Dunajská Streda	21	3	28	52
Galanta	19	4	13	36
Hlohovec	1	7	12	20
Piešťany	12	7	9	28
Senica	18	5	20	43
Skalica	9	7	15	31
Trnava	6	6	7	19
Total	**86**	**39**	**104**	**229**
Bánovce n. Bebravou	2	2	3	7
Ilava	14	0	2	16
Myjava	5	2	5	12
Nové Mesto n. Váhom	9	8	10	27
Partizánske	2	4	5	11
Považská Bystrica	10	2	2	14
Prievidza	6	10	24	40
Púchov	4	3	11	18
Trenčín	15	6	9	30
Total	**67**	**37**	**71**	**175**
Komárno	13	5	18	36
Levice	19	6	17	42

Nitra	23	7	21	51
Nové Zámky	28	10	31	69
Šaľa	13	5	5	23
Topoľčany	7	2	5	14
Zlaté Moravce	15	4	14	33
Total	**118**	**39**	**111**	**268**
Bytča	21	0	3	24
Čadca	7	5	7	19
Dolný Kubín	2	4	7	13
Kysucké N. Mesto	3	5	4	12
Liptovský Mikuláš	35	6	36	77
Martin	5	1	9	15
Námestovo	3	1	3	7
Ružomberok	12	4	11	27
Turčianske Teplice	0	0	3	3
Tvrdošín	4	2	4	10
Žilina	15	6	5	26
Total	**107**	**34**	**92**	**233**
Banská Bytrica	21	8	10	39
Banská Štiavnica	6	3	8	17
Brezno	15	7	14	36
Detva	2	3	5	10
Krupina	2	1	6	9
Lučenec	8	4	7	19
Poltár	2	2	4	8
Revúca	7	1	7	15
Rimavská Sobota	18	5	12	35
Veľký Krtíš	5	2	10	17
Zvolen	9	8	15	32
Žarnovica	16	0	4	20
Žiar nad Hronom	13	5	9	27
Total	**124**	**49**	**111**	**284**
Bardejov	28	4	12	44
Humenné	16	4	9	29
Kežmarok	15	4	13	32
Levoča	12	1	8	21
Medzilaborce	9	1	2	12
Poprad	18	6	35	59
Prešov	10	4	16	30
Sabinov	3	2	6	11
Snina	12	2	9	23
Stará Ľubováa	10	1	7	18
Stropkov	8	4	4	16
Svidník	12	2	6	20
Vranov n. Topľou	33	5	15	53
Total	**186**	**40**	**142**	**368**
Košice I.-IV.	2	7	23	32
Gelnica	15	3	13	31
Košice okolie	16	5	14	35
Michalovce	13	12	25	50
Rožňava	14	5	18	37
Sobrance	5	0	3	8

Spišská Nová Ves	6	8	18	32
Trebišov	13	3	22	38
Total	**84**	**43**	**136**	**263**
Slovak Republic	**852**	**324**	**852**	**2 028**

Source: Own processing according to the Information system on environmental burdens

The following Table 2 documents the occurrence of environmental burdens on the territory of Slovakia by individual regions, districts and by groups (A, B and C) of environmental burdens management in 2021.

Table 2. Allocation of environmental burdens according to individual types within the districts in the territory of the Slovak Republic in 2021

District	Type A	Type B	Type C	Total
Bratislava I.-V.	33	26	40	99
Malacky	28	4	20	52
Pezinok	9	9	7	25
Senec	11	2	16	29
Total	**81**	**41**	**83**	**205**
Dunajská Streda	21	2	26	49
Galanta	20	4	13	37
Hlohovec	1	7	11	19
Piešťany	13	7	8	28
Senica	19	4	20	43
Skalica	9	8	15	32
Trnava	6	6	7	19
Total	**89**	**38**	**100**	**227**
Bánovce n. Bebravou	2	2	2	6
Ilava	14	0	2	16
Myjava	5	2	4	11
Nové Mesto n. Váhom	9	8	10	27
Partizánske	2	4	5	11
Považská Bystrica	10	2	2	14
Prievidza	6	12	23	41
Púchov	4	4	10	18
Trenčín	17	5	9	31
Total	**69**	**39**	**67**	**175**
Komárno	13	6	16	35
Levice	19	6	16	41
Nitra	25	6	21	52
Nové Zámky	30	12	30	72
Šaľa	14	5	5	24
Topoľčany	7	2	5	14
Zlaté Moravce	17	4	13	34
Total	**125**	**41**	**106**	**272**
Bytča	21	0	3	24
Čadca	7	5	6	18
Dolný Kubín	2	5	5	12
Kysucké N. Mesto	4	6	4	14
Liptovský Mikuláš	35	6	35	76
Martin	5	2	7	14
Námestovo	3	1	3	7
Ružomberok	15	3	11	29
Turčianske Teplice	0	0	3	3

Tvrdošín	4	2	3	9
Žilina	15	6	5	26
Total	**111**	**36**	**85**	**232**
Banská Bytrica	23	6	10	39
Banská Štiavnica	7	2	6	15
Brezno	15	8	13	36
Detva	2	3	5	10
Krupina	2	1	6	9
Lučenec	8	4	7	19
Poltár	2	2	4	8
Revúca	7	1	7	15
Rimavská Sobota	17	6	12	35
Veľký Krtíš	5	2	10	17
Zvolen	9	8	14	31
Žarnovica	16	0	4	20
Žiar nad Hronom	13	5	9	27
Total	**126**	**48**	**107**	**281**
Bardejov	28	4	11	43
Humenné	15	4	8	27
Kežmarok	15	4	12	31
Levoča	12	1	8	21
Medzilaborce	10	1	2	13
Poprad	19	5	35	59
Prešov	10	4	15	29
Sabinov	3	2	6	11
Snina	13	1	9	23
Stará Ľuboväa	10	1	7	18
Stropkov	8	4	4	16
Svidník	14	2	6	22
Vranov n. Topľou	34	5	15	54
Total	**191**	**38**	**138**	**367**
Košice I.-IV.	3	8	22	33
Gelnica	15	3	13	31
Košice okolie	16	5	14	35
Michalovce	13	12	24	49
Rožňava	14	5	17	36
Sobrance	5	0	3	8
Spišská Nová Ves	8	6	17	31
Trebišov	13	3	22	38
Total	**87**	**42**	**132**	**261**
Slovak Republic	**879**	**323**	**818**	**2 020**

Source: Own processing according to the Information system on environmental burdens

4. Discussion

The data in 2025 show that the highest occurrence of environmental burdens in the territory of the Slovak Republic was recorded in the Prešov and Banská Bystrica regions. The smallest share was recorded in the Trenčín Region, the second smallest share of environmental burdens was recorded in the Bratislava Region. Interestingly, the total number of environmental burdens on the territory of Slovakia in 2025 (as of 15 April 2025) in the group of type A is the same as the number of burdens in the group of type C. These findings are documented in Table 3 below.

Table 3. Allocation of environmental burdens according to individual types within the regions in the territory of the Slovak Republic in 2025

Region	Type A	Type B	Type C	Total
Bratislavský	80	43	85	208
Trnavský	86	39	104	229
Trenčiansky	67	37	71	175
Nitriansky	118	39	111	268
Žilinský	107	34	92	233
Banskobystrický	124	49	111	284
Prešovský	186	40	142	368
Košický	84	43	136	263
Total	**852**	**324**	**852**	**2 028**

Source: Own processing according to the Information system on environmental burdens

Chart 1 documents an overview of the occurrence of environmental burdens on the territory of the Slovak Republic in 2025 according to individual regions and also according to groups A, B and C of environmental burdens management.

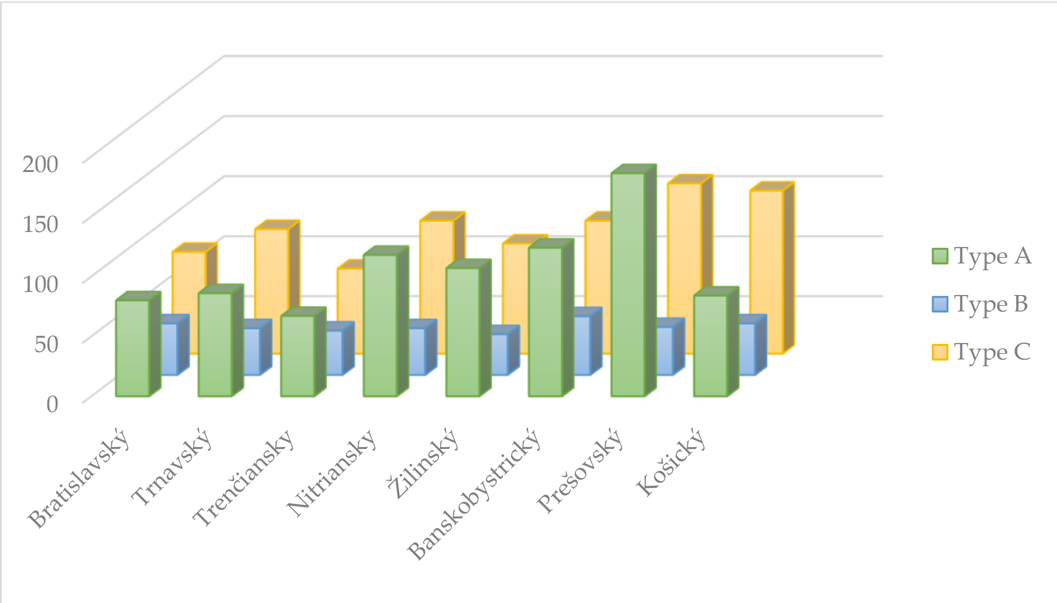

Chart 1. Allocation of environmental burdens according to individual types within the regions in the territory of the Slovak Republic in 2025
Source: Own processing according to the Information system on environmental burdens

In 2021, the highest incidence of environmental burdens in the Slovak Republic was recorded in the Prešov and Banská Bystrica regions. The smallest share was recorded in the Trenčín Region, the second smallest share of environmental burdens was recorded in the Bratislava Region. These findings are documented in Table 4 below. The data show that the occurrence of environmental burdens in individual regions in Slovakia in 2025 does not differ significantly from the situation in 2021.

Table 4. Allocation of environmental burdens according to individual types within the regions in the territory of the Slovak Republic in 2021

Region	Type A	Type B	Type C	Total
Bratislavský	81	41	83	205
Trnavský	89	38	100	227
Trenčiansky	69	39	67	175
Nitriansky	125	41	106	272
Žilinský	111	36	85	232

Banskobystrický	126	48	107	281
Prešovský	191	38	138	367
Košický	87	42	132	261
Total	**878**	**323**	**818**	**2 020**

Source: Own processing according to the Information system on environmental burdens

Chart 2 documents an overview of the occurrence of environmental burdens on the territory of the Slovak Republic in 2021 according to individual regions and also according to groups A, B and C of environmental burdens management.

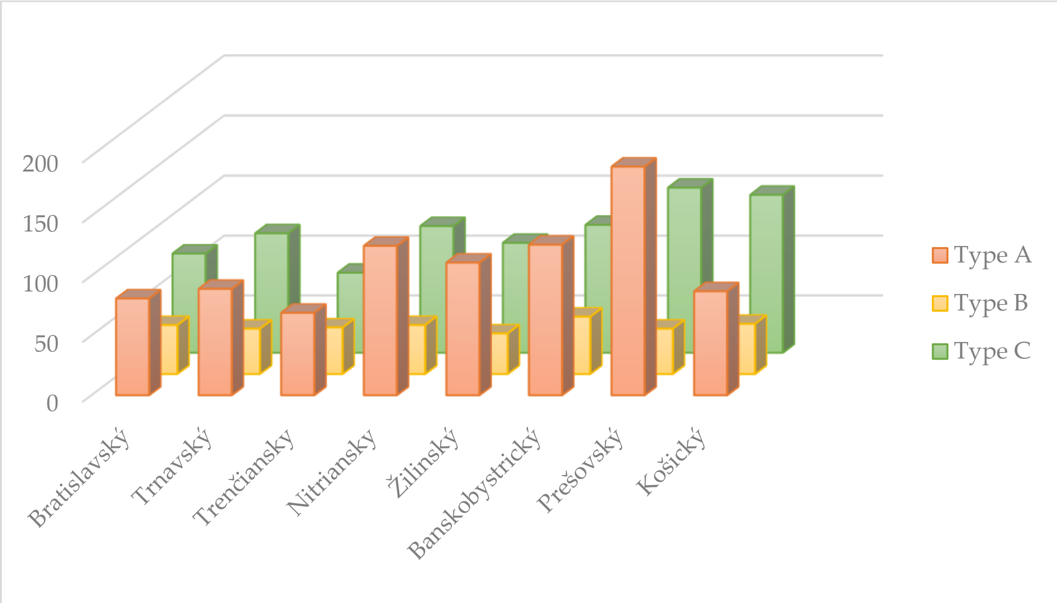

Chart 2. Allocation of environmental burdens according to individual types within the regions in the territory of the Slovak Republic in 2021
Source: Own processing according to the Information system on environmental burdens

5. Conclusion

The results of our research show that the number of environmental burdens on the territory of Slovakia in 2025 increased compared to 2021 by a total of 8 registered burdens. The ranking of individual regions did not change during the period under review and the number of environmental burdens in the regions of the Slovak Republic did not experience a large increase. Table 5 below shows the ranking of the individual regions of the Slovak Republic according to the number of environmental burdens located on the territory of the given region in 2025 and 2021.

Table 5. Occurrence of environmental burdens within the regions in the territory of the Slovak Republic

Region	2025	2021
1. Prešovský	368	367
2. Banskobystrický	284	281
3. Nitriansky	268	272
4. Košický	263	261
5. Žilinský	233	232
6. Trnavský	229	227
7. Bratislavský	208	205
8. Trenčiansky	175	175
Total	**2 028**	**2 020**

Source: Own processing according to the Information system on environmental burdens

The results of the research published in the present paper create room for a deeper investigation of environmental burdens in the Slovak Republic. For the needs of further research it would be beneficial to analyse in more detail the causes of environmental burdens in individual territories, as well as realistic options for their solution.

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Business conditions in Slovakia and their connection with financing small and medium-sized enterprises

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Abstract: The main driving force of entrepreneurship is the pursuit of success. Success can take many forms, depending on the specific preferences of company owners. Success is primarily monetary, but it can also involve goals that are more difficult to express financially. For example, such an alternative to success is world-recognized innovation, a prestigious reputation thanks to responsible entrepreneurship, etc. We can also understand success on a smaller scale. In times of crisis, it can be about maintaining the quality of one's production, maintaining customer loyalty, having enough financial resources for one's existence, and the like. Everything will ultimately be reflected in financial results. It is essential for the owner to increase one's wealth. The text contains ideas that point to some milestones of businesses on the way to their success. The article focuses on assessing the conditions of doing business in Slovakia and their relationship with the financing scenarios of small and medium-sized enterprises. The result of the analysis of the multi-criteria assessment of Slovakia is the identification of its most serious negative aspects. The biggest obstacle has been shown to be government integrity and government spending. The business success of a selected set of enterprises is monitored in this paper based on an analysis of their financing methods, which is put into context with the negative characteristics of Slovakia. A mostly negative, moderately strong relationship between corporate indebtedness and Slovakia's weaknesses has been demonstrated.

Keywords: business conditions; multi-criteria evaluation; analysis; comparison; correlation; debt indicators

Introduction

The success of a business depends on a number of factors, only some of which an entrepreneur can control. He can control and directly manage only a smaller part of them. The entrepreneur first of all decides when, how much and in what to invest. Investments are the driving force of businesses. They stimulate human and production capital to activities, thus creating the possibility of success and obtaining an interesting financial effect for his own needs. Business activities cannot be implemented without a mix of financial resources. The volume of own resources is directly determined by state legislation, the business and its owners, and indirectly by the state of the global and national economy. Drawing on external resources generally depends on the condition of financial markets, the attractiveness of investment projects and the condition of applicants. The financial consequences of financing for the business are ultimately determined by the resulting combination of own and external resources. The paper aims to assess the various factors that shape the conditions for doing business in Slovakia and to find relationships between selected characteristics of Slovakia and scenarios for financing small and medium-sized enterprises. The state of financing of small and medium-sized enterprises is clarified by the latest knowledge on the determinants of financing.

1. Literature Review

The factors of entrepreneurship have received relatively little attention in research so far. Research results show that entrepreneurship can be viewed from many angles, but the basics are generally the same. Entrepreneurship is based on basic production factors (labor, land, capital), to which minimal information is currently required. At the same time, a business is in constant interaction with its immediate and distant surroundings, so it is important to be interested in this aspect of entrepreneurship on a daily basis. Efficient use of production factors, working with relevant information in real time, and stimulating relationships between a business and its surroundings is the path to prosperous and sustainable entrepreneurship. If quality conditions for entrepreneurship are created and businesses know how to benefit from them, then not only their competitiveness increases, but also the competitiveness of the entire country. The European Union has so far been the driving force behind the economic growth of its members, but it is currently starting to lag behind in this regard. The EU's lagging in economic growth since 2008 is aptly characterised by Ketels and Porter (2021). Their research suggests that the underperformance of EU members is not only caused by ineffective policy decisions, but also by a stagnant approach to increasing competitiveness. The EU should support its regions and countries according to their specific circumstances. Competitiveness is by its nature highly context-dependent and requires strong local and national leadership. Competitiveness has been the focus of much research over the past 34 years. The most publications on competitiveness are to be found in the journals Competitiveness Review, World Development and Applied Economics. Porter stands out as an author of articles on international competition. He draws on collaborations mainly with universities in Southeast Asia. Western European countries are studied separately and BRICS countries are usually studied together (Capobianco-Uriarte et al., 2019).

The results of numerous studies have materialized into monitoring the competitiveness of countries in the form of competitiveness indices and compiled country rankings. For example, the IMD World Competitiveness Ranking has a 36-year history. In 2024, 67 countries of the world were compared with each other. The final score for each economy is calculated based on the evaluation of the collected opinions of managers together with statistical data. The scores for economic performance, government efficiency, business efficiency and infrastructure are published separately. These main groups of indicators are further divided into 5 subcategories. Economic performance includes an assessment of the domestic economy, international trade, international investments, employment and prices. Government efficiency covers public finances, tax policy, institutional framework, trade legislation and social framework. Business efficiency includes productivity and efficiency, the labor market, finances, management practices, attitudes and values. The final category, infrastructure, summarizes the scores for basic, technological and scientific infrastructure, health and environment, and education.

Another example, this time with a 31-year history, is the compilation of the Index of Economic Freedom of the respective countries, published by the Heritage Foundation. The index essentially expresses the level of freedom for business. In an economically free society, individuals are free to work, produce, consume and invest in any way they see fit. The index includes 12 freedoms, from property rights to financial freedom in 184 countries. These 12 quantitative and qualitative factors are divided into four categories. The first category is called the rule of law, which includes property rights, government integrity, and judicial efficiency. The second category is the size of government, assessed according to public spending, tax burden and fiscal health. The third part is regulatory efficiency, monitored in terms of business freedom, labor freedom and monetary freedom. The final component is called open markets and concerns trade freedom, investment freedom and financial freedom. The individual freedom categories are rated on a scale from 0 to 100. All components are equal, so they are combined into an overall score by averaging them. The data obtained so far confirms that economic freedom brings prosperity.

Between the level of business factors in a given country and the financial results of enterprises. The basic condition for sustainable business is sound finances. Supervision over the condition of finances is carried out by a financial manager, whose main task is to secure finances in the required volume and time from sources that are to be tailored precisely to the enterprise. Optimally adapting financing to the needs of the enterprise is not an easy task. The determinants of the financial structure play an important role in this task. Extensive research activity has contributed to the definition of a set of determinants, but research in this area is still not complete. Managing the financial structure is constantly enriched with new contexts, therefore, to date, there is no clear universal guide to achieving an optimal financial structure. Lourenço and Oliveira (2017) divided theoretical knowledge into two main streams, namely the traditionalist optimization of financial structure, which leads to the maximization of firm value, and the theory of irrelevance of financial structure, which was established by Modigliani and Miller as early as 1958. Modigliani and Miller's ideas became the impetus for the birth of the trade-off theory, which understands financial structure decisions as a compromise between the advantages interest tax shield and the costs of financial hardship. Financial difficulties are caused by excessive corporate indebtedness, which could lead to an excessive focus on obtaining the interest tax shield. According to Henrike et al. (2018), the trade-off theory considers the target financial structure that a company would pursue. Heckenbergerová and Honková (2023) add that the central idea is to prefer debt financing over equity up to a critical financial level. Despite interesting observations, the concept of trade-off theory cannot explain why some very profitable companies tend to be less indebted. The hierarchical order theory offers a response to this phenomenon. The theory stems from the existence of information asymmetry between managers, owners and investors from the external environment, which is why it also divides financial resources into internal and external. It even divides equity capital into internal and external. In the hierarchical arrangement, internal equity appears in the first place and external equity resources appear at the bottom of the list. In accordance with the hierarchy defined in this way, internal financing is used to the maximum extent possible, followed by external debt financing. If this is not enough due to investment opportunities, only then does the company reach for its own resources from the external environment. The theory of hierarchical order points out that companies with a higher level of long-term tangible assets are less prone to information asymmetry, therefore they are less likely to use external resources; we can therefore assume a negative correlation between the asset structure and the indebtedness of the companies studied (Vatavu 2013; Anderloni and Tanda 2014). The basic concept of the trade-off theory and the theory of hierarchical order is in opposition. The asymmetry in information ultimately resulted in a signaling model of capital structure. The intensity of debt financing and the structure of debts are perceived as signals about the company to the external environment. Only companies with investment opportunities and sufficiently high profitability can prevent financial difficulties even with a higher level of debt. Several authors have recently addressed the application of the aforementioned theories of financial structure optimization in business practice, e.g. Ngatno et al. (2021), Delikanli (2020). Through empirical studies, they tried to verify the validity of the theories and enrich them with new contexts. Nguyen et al. (2006) were interested in the impact of family ownership on the speed of a company's adaptation to the target capital structure in the sense of the trade-off theory. They conducted their research on a sample of ASEAN countries. They found that family businesses adapt their capital structure more slowly. This is due to higher costs, high information asymmetry and conflicts of interest between family owners and external investors. The impact of family ownership on the speed of capital structure adjustment is more pronounced when family businesses have a higher level of family involvement in the board of directors and higher ownership concentration. Mhiri et al. (2025) were interested in the impact of cultural dimensions on the relationship between corporate social responsibility and their financial decisions. They based their conclusions on an analysis of 780 non-financial companies for the period 2011 to 2021. They obtained strong evidence of a negative association between corporate social responsibility and the use of debt financing. Rocciolo et al. (2024) develop and empirically test the choice of capital structure when CEOs are overly cautious. Companies led by overly cautious CEOs are more likely to have zero or near-zero debt. Irrational CEOs adjust to the optimal debt level more slowly than rational ones. A new contribution to the theory of hierarchical order was made by Ezeani et al. (2025) by investigating the relationship between managers' characteristics and their financial decisions. They arrived at their results based on observations of 18,235 listed Chinese firms. They proved the existence of a positive relationship between CEO age and debt, especially in state-owned enterprises. Young CEOs use less debt. Interesting observations regarding the existence of herding behavior in the formation of capital structure are provided by the work Golubić et al. (2025). The authors conducted an analysis on publicly listed companies in several developed European markets in the period from 2000 to 2023. The results confirm the existence of a herd effect on capital structure decisions. Herding behavior is more pronounced in certain countries and sectors. It is most pronounced in the United Kingdom and to a lesser extent in Switzerland and France. Overall, it was confirmed that companies do not make their capital structure decisions in isolation. Companies from different sectors or countries are more or less influenced by the actions of their competitors. A more common part of the research by Pham and Hrdý (2023) , Chandra et al. (2022), He and Ausloos (2017) , Lourenço and Oliveira (2017) mapping the pre-crisis and crisis periods is the non-debt tax shield, which is related to the depreciation of a company's long-term assets. Depreciation is fully recognized as a tax expense, which reduces the tax burden on the company. In addition, owning long-term assets and taking care of their condition gives companies the opportunity to provide banks with adequate collateral for the required interest-bearing debt. A high share of tangible assets in total assets allows for an increase in the share of debt in the financial structure. When deciding on the financial structure, it is important to consider the tax shield effect only in the case of balanced operating results, a higher interest rate on debt combined with a level of taxation that will increase the wealth of owners. Văidean and Vaida (2017) point out the different tax consequences of debt and equity for a company. Interest-bearing debt is usually associated with an interest tax shield, in accordance with the diction of the state's tax legislation. More interest-bearing debt brings a company higher tax savings, thereby reducing its financing costs. Legislation through income taxation affects the profitability of equity capital in a different way, i.e. higher taxation reduces profit and weakens the possibilities of internal financing of the needs of the company. The authors divide their research into a group of internal and external factors. Jaworski and Czerwonka (2019) assume that the strength and direction of internal factors can be shaped by external factors – macroeconomic and institutional specifics of the business environment. Their research confirmed the existence of a statistically significant relationship between four external factors (inflation, GDP growth rate, GDP, degree of protection of creditors' and debtors' rights) and the strength and direction of the influence of internal factors on the capital structure. They argue that the larger the economy (it has a higher GDP), the more significant the positive impact of the share of long-term assets on total assets on the company's debt. In richer economies, the larger the company, the less indebted it is. The richer the citizens of a country (the higher the GDP/inhabitants), the stronger the positive effect of the size of a company on its indebtedness. The faster the economy grows (the higher the GDP growth rate), the stronger the negative relationship between the non-debt tax shield and corporate indebtedness. In economies with high inflation, the growth of the non-debt tax shield causes a stronger increase in corporate indebtedness. In countries with higher unemployment, the asset structure has a more significant negative effect on corporate indebtedness. Finally, they confirmed that in economies with easier access to credit, an increase in the size of a company causes a dynamic increase in its indebtedness. Růčková and Škuláňová (2022) focused on testing the impact of internal and external factors on the level of short-term, long-term and total debts. They processed data on construction companies from the V4 countries, Austria, Bulgaria, Slovenia and Romania. They confirmed that the financial structure of construction companies is most influenced by external factors of the macro environment. Small and medium-sized enterprises were the focus of Mazanec (2023) , D'Amato (2020), who emphasized that these enterprises significantly reduced their leverage during the global financial crisis. They used trade loans the most. Financing was studied by Degryse, de Goeij and Kappert (2021) who studied financing in small and medium-sized enterprises. Dutch firms , Czerwonka and Jaworski (2021) in Polish, Czech, Slovak, Hungarian, Bulgarian and Romanian firms , Palacín-Sánchez, Ramírez-Herrera, and di Pietro (2012) with a sample of 13,838 firms, Nunes et al. (2010) with a sample of 273 firms, Psillaki and Daskalakis (2009) with a sample of 320 Greek, French, Italian and Portuguese firms. It has been shown that differences in the choice of capital structure of SMEs are explained by firm-specific factors rather than country-specific influences.

2. Methodology

The article offers a search of the latest knowledge about entrepreneurship and factors that influence entrepreneurship. The research results are transferred to a multi-criteria assessment of countries in terms of their competitiveness, or rather the ability to provide acceptable conditions for entrepreneurial activities. The presented analysis is focused on determining the strengths and weaknesses of Slovakia, stemming from a relatively wide spectrum of assessed quantitative and qualitative factors. The analysis respects the methodology of global assessment of the competitiveness of countries, long used by the Center for World Competitiveness IMD and the methodology of the Index of Economic Freedom, published by the Heritage Foundation, the most important Washington expert team. The objectivity of the conclusions of the analysis is achieved by comparing the score of Slovakia with other assessed countries, mainly with the V4 countries. The informative value of the analysis is specified by the mutual confrontation of Slovakia's scores, obtained by the mentioned assessment methodologies. The selection of data ensures the clarity and logic of the facts provided about the conditions created for entrepreneurship in Slovakia. Induction and deduction allow us to specify the informative value of the analyzed data. Sustainable entrepreneurship is based on adequate financing, therefore the issue of evaluating Slovakia is connected with the analysis of its relationship with the financial structure of enterprises. Financing of small and medium-sized enterprises is assessed using quartile values of debt ratios. Variability of debt ratios is expressed by quartile deviations. The time series of debt ratios is used to calculate the correlation with the identified prominent negative aspects of Slovakia. A series of factor scores monitored in the evaluation of Slovakia by the Index of Economic Freedom is adapted to the time series of debt ratios.

3. Results

The main theme of the article is to monitor the conditions for doing business in Slovakia from different perspectives and connect them with the financing of small and medium-sized enterprises. The initial characteristic of Slovakia is provided by the IMD World Competitiveness Ranking, which is based on a maximum score of 100. Among 67 countries, Singapore, Switzerland and Denmark took the top 3 positions in 2024. Singapore's total score is 100 and the other two countries have scores slightly above 97. The ranking was closed by Ghana, Argentina and the very last Venezuela with a score of 28.9. The Czech Republic defended its 29th place, Poland 41, Hungary 54 and Slovakia 59. The resulting score for Slovakia is 46.9 and for the Czech Republic 70.2. From 2020 to 2022, Slovakia's position improved, but in the last two we have been gradually falling, until we are 2 places lower in the ranking than in 2020. Our fall was only slightly mitigated by the domestic economy, international trade, business productivity and efficiency, and management practices. Details about Slovakia are summarized in Figure 1. It is clearly seen that our ratings are not even half the level of the best countries in all respects. From several points of view, we are even very close to Venezuela.

Figure 1. Characteristics of Slovakia according to the IMD World Competitiveness Ranking

Source: own processing from https://www.imd.org/centers/wcc/world-competitiveness-center/rankings/world-competitiveness-ranking/rankings/wcr-rankings/#_tab_List

Slovakia's biggest weaknesses are business efficiency and government efficiency. Government efficiency is the weakest due to public finances with a score of 27.8 and business legislation with a score of 28.4. Business efficiency is harmed by attitudes and values with a score of 1, along with the labor market with a score of 30 and finances with a score of 29.1. We can confirm that entrepreneurs are improving their business management skills despite many obstacles and thus increasing their productivity and efficiency.

The characteristics of Slovakia are specified by the second multi-criteria assessment publicly published in the form of the Index of Economic Freedom. Today, Slovakia ranks 42nd out of 176 countries in the world. It is ranked in the last quarter of the evaluated countries, i.e. in the upper quartile. Slovakia has long been included among countries with moderate economic freedom. The degree of freedom or lack of freedom is limited by the resulting values of the index, shown in Table 1.

Table 1. Overview of economic freedom bands

Index/Band	Freedom	Mostly freedom	Moderate freedom	Mostly unfreedom	Suppression of freedom
Score	100-80	79.9-70	69.9-60	59.9-50	49.9-0

Source: Own processing based on the methodology for compiling the Index of Economic Freedom

Only 3 countries (Singapore, Switzerland and Ireland) scored above 80, so we can consider them as economically free. 26 countries have earned the designation "mostly free", 58 countries are rated as "partly free". Not even half of the 176 countries in the world are now moderately or more free. 60 countries are not free, i.e. 34%, and 29 countries (approx. 16.5%) "suppress freedom". The level of economic freedom is most favorable in Europe. Europe is followed by the Americas, the Middle East and North Africa, Asia and the Pacific, and the most unfavorable situation is in Sub-Saharan Africa.

Slovakia has fallen behind the Czech Republic among the V4 countries. It has overtaken Poland and Hungary. As shown in Figure 2, the Czech Republic is in the more successful group of countries with a predominance of economic freedom. The opposite pole is Hungary, which has come dangerously close to the border with a predominance of unfreedom.

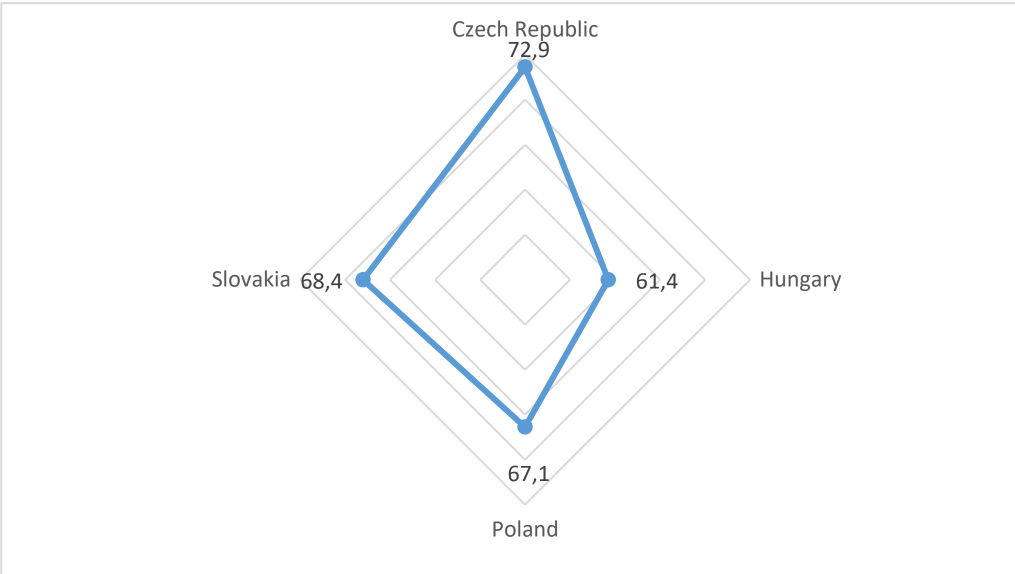


Figure 2. Comparison of Slovakia with the V4 countries.

Source: Own processing from https://www.heritage.org/index/pages/all-country-scores

The question is what improves Slovakia's position and what worsens it. The answers are offered in Figure 3, which shows the scores of individual factors of economic freedom in the V4 countries.

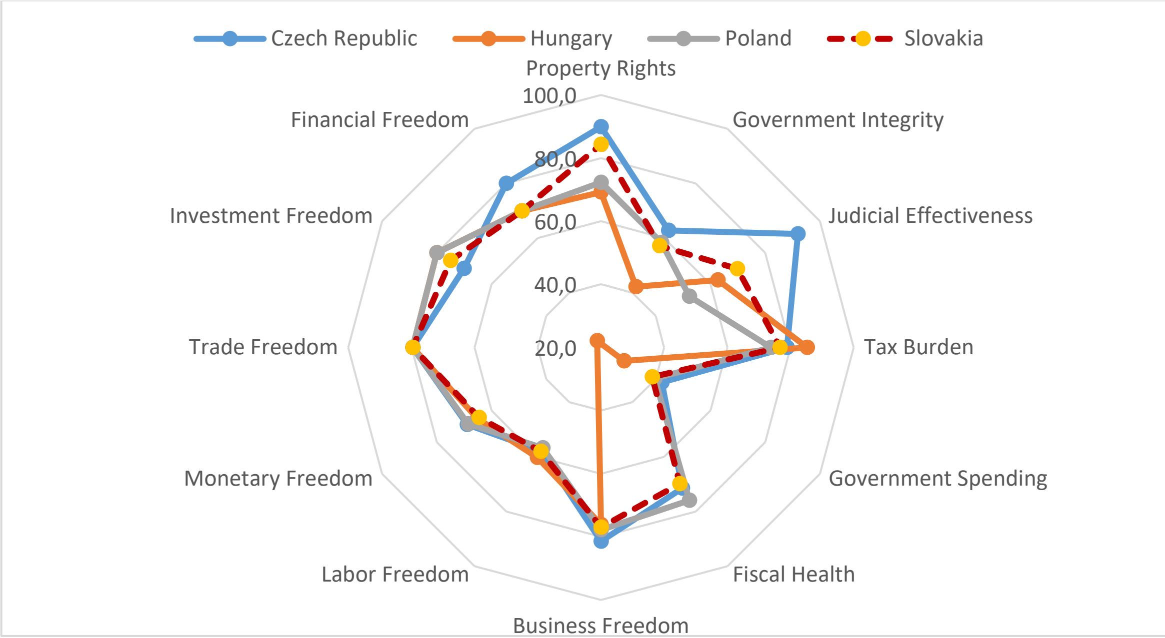
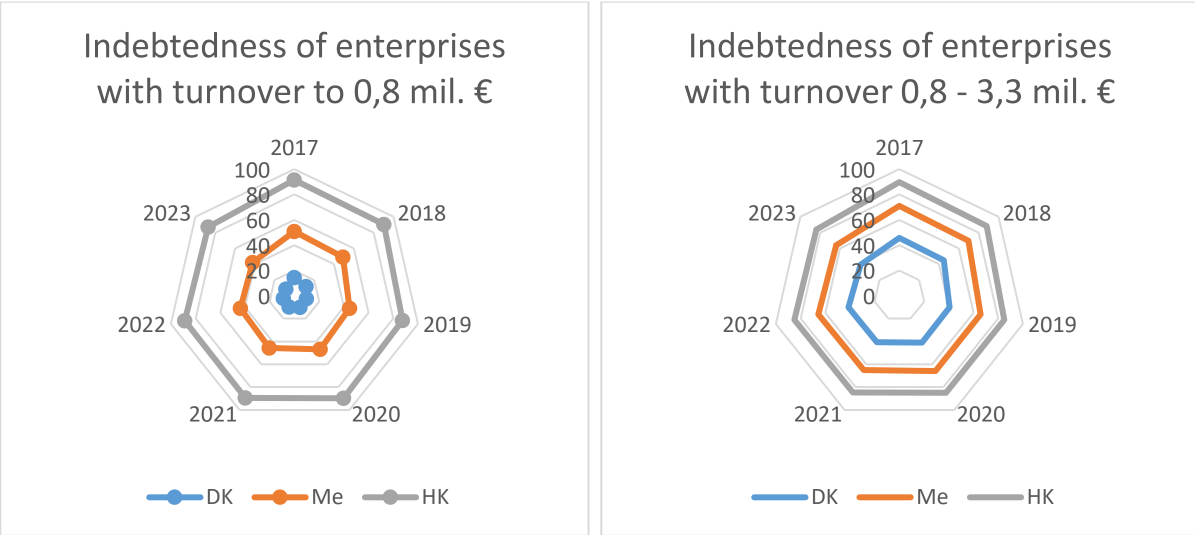


Figure 3. Comparison of Slovakia's economic freedom factor scores with the V4 countries.

Source: Own processing from https://www.heritage.org/index/pages/all-country-scores

The 2025 index was created based on data from 2024, so we have a better assessment of the preservation of property rights and the effectiveness of the judiciary. The data from 2025, incorporated into the 2026 index, may already indicate something different about the efficiency and fairness of the judiciary. Despite the fact that these are our better aspects, we were not able to overtake the Czech Republic in any of them. In terms of judicial effectiveness, we are even the furthest from the Czech Republic. The V4 countries are most similar in trade freedom and labor freedom. Due to their open economies, the countries do not create unnecessary obstacles to trade. There is rather a predominance of unfreedom on the labor market, which may be more related to the conclusion of employment contracts. Slovakia's greatest weaknesses are government spending and government integrity. These weaknesses are so great that in this regard we are assessed as a country with prevailing unfreedom, or even one that suppresses freedom. High government spending, which is also poorly structured, is very harmful to our economy. High spending increases the demands for securing increasingly missing funds in the state budget and causes losses in consumption and investment. Government indiscipline leads to lower production, inefficiency and growing public debt. Increasing public debt will be an unpleasant burden for future generations. Corruption, bribery, clientelism, embezzlement, in turn, limit economic freedom and hinder the country's competitiveness. Inappropriate government intervention in economic activity exacerbates the problem of corruption even more. It turns out that both presented approaches to assessing Slovakia agree in identifying our weakest points. It seems that the current and future governments of Slovakia have the most difficult domestic task.

The identified negative aspects of Slovakia lead us to reflect on the issue of financing businesses, especially small and medium-sized enterprises. It can be assumed that the current domestic and global policy will continue to weaken economic growth in the near future. Low economic growth limits the creation of own sources of financing and increases the price of foreign sources. Figure 4 shows published data on the financing of small and medium-sized enterprises operating in Slovakia. The data is provided by CRIF – Slovak Credit Bureau, sro The company's application with ratio financial indicators is called CRiBiS.Sk. The result of statistical processing are the quartile values of the most commonly used set of indicators in practice, from which indicators characterizing the financing of businesses are selected in view of the topic of the contribution. Specifically, these are total, long-term and credit indebtedness. Furthermore, the indebtedness indicators include the ratio of equity to liabilities, interest coverage and current indebtedness. In connection with self-financing, the ROE indicator is also interesting. The paper publishes debt data from 2017 to 2023. More recent data are not available at the time of writing. The time series will serve to quantify the correlation between financing indicators and the most serious negative aspects of Slovakia, resulting from the initial analyses mentioned above.



(**a**) (**b**)

Figure 4. Indebtedness of enterprises: (**a**) small enterprises; (**b**) medium-sized enterprises.

Source: Own processing

The figure shows that the interquartile range of total debt is much larger for small enterprises. The mean value of the variance of small enterprise debt is approximately 39 to 40 percentage points. The mean value of the variance of medium-sized enterprises debt is 22 percentage points. Small enterprises are typically less indebted than medium-sized enterprises. Their typical debt has gradually decreased over the period under review , from a peak of approximately 51% in 2017 to approximately 42% in 2023. Small enterprises have been trying to minimize their financing risk over time. However, the threshold separating the most indebted enterprises is very high. The upper quartile (UQ) of total debt for small enterprises is even slightly higher than the UQ of medium-sized enterprises. Table 2 provides further details on the financing of small enterprises.

Table 2. Indebtedness indicators of companies with turnover up to €0.8 million

Indicator	Q	2017	2018	2019	2020	2021	2022	2023
Long-term debt	DK	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Me	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	HK	1.16	1.44	1.68	1.84	1.76	1.71	1.71
Credit indebtedness	DK	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Me	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	HK	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VI to liabilities ratio	DK	0.09	0.11	0.14	0.12	0.12	0.13	0.15
	Me	0.98	1.05	1.25	1.14	1.20	1.29	1.39
	HK	6.00	7.41	9.23	8.95	9.29	10.31	10.93
Interest coverage	DK	inf	inf	inf	inf	inf	inf	inf
	Me	74.12	23.71	23.31	8.73	13.11	15.86	20.80
	HK	inf	inf	inf	inf	inf	inf	inf
Debt repayment period	DK	1.44	1.42	1.22	1.49	1.40	1.30	1.15
	Me	8.89	8.64	7.60	10.51	9.55	8.96	7.57
	HK	inf	inf	inf	inf	inf	inf	inf
ROE	DK	-21.57	-12.26	-10.88	-17.81	-13.84	-11.14	-7.77
	Me	5.92	3.46	3.07	1.33	1.82	2.14	2.96
	HK	30.43	27.87	27.45	23.87	24.79	24.76	26.66

Source: Own processing based on the CRiBiS database - universal register

Almost all debts of small businesses have short maturities. The HK defines the financing of assets with long-term debts from 1.16% to a maximum of 1.84%. Approaching 2% of the financial coverage of assets with long-term resources is in favor of the financial stability of small businesses. Small businesses do not have credit resources at the end of the accounting period, therefore the interest coverage indicator does not have the necessary informative value. The abbreviation inf indicates extreme values. The least indebted small businesses (from approximately 14% in 2017 to approximately 8% in 2023) probably repay their debts very quickly. The longest is up to 1.49 years, which is indicated by the DK values. The median maturity of debts between approximately 8 and 11 years is disproportionately long given the lower current indebtedness of small businesses. This is most likely a consequence of the weaker profitability of this group of businesses. It seems that small businesses are not at risk of bankruptcy dramatically due to their significant self-financing. According to the Commercial Code, businesses are at risk of bankruptcy if the ratio of VI to liabilities is less than 6 to 100 in 2017 and less than 8 to 100 in 2018 and in subsequent years. The reason for the moderate indebtedness of small businesses is the already assumed lower level of profitability. The least successful small businesses regularly generate losses (as evidenced by the DK ROE). They usually have a return on equity of 1.33% to 5.92%. The decline in profitability occurred during the Covid period. The situation is gradually improving, but at an insufficient pace. ROE still does not reach the level of 2017.

The situation appears similar in the case of medium-sized enterprises. Their financing risk is generally not above standard and is decreasing over time. Their current debt ratio has fallen from a peak of approximately 71% in 2017 to almost 64% in 2023. These are larger enterprises, which is why their debt ratio is slightly higher than that of the group of small enterprises. The threshold value of the most indebted medium-sized enterprises is somewhat more acceptable compared to small enterprises. Table 3 shows other characteristics of the debt ratio of medium-sized enterprises.

Table 3. Indebtedness indicators of companies with a turnover of 0.8 – 3.3 million €

Indicator	Q	2017	2018	2019	2020	2021	2022	2023
Long-term debt	DK	0.11	0.13	0.16	0.15	0.15	0.16	0.17
	Me	1.91	2.13	2.23	2.63	2.64	2.49	2.64
	HK	14.68	14.88	14.85	16.93	17.01	16.74	16.79
Credit indebtedness	DK	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Me	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	HK	11.31	11.34	11.69	13.74	14.43	13.99	13.78
VI to liabilities ratio	DK	0.12	0.14	0.18	0.185	0.19	0.18	0.20
	Me	0.42	0.45	0.54	0.53	0.55	0.54	0.58
	HK	1.23	1.27	1.52	1.49	1.51	1.46	1.61
Interest coverage	DK	2.40	2.44	2.35	2.20	3.28	3.54	2.44
	Me	18.29	18.7	19.41	18.23	26.17	24.92	18.22
	HK	inf	inf	inf	4954.64	inf	86887.00	inf
Debt repayment period	DK	2.91	2.76	2.53	2.56	2.36	2.30	2.23
	Me	7.07	6.72	6.08	6.26	5.70	5.69	5.56
	HK	19.86	18.74	16.01	17.65	15.23	14.94	15.16
ROE	DK	1.99	2.15	1.87	1.60	3.31	3.65	3.04
	Me	16.19	15.26	13.62	13.87	15.98	17.06	15.77
	HK	44.32	41.08	36.87	35.94	39.37	39.76	39.06

Source: Own processing based on the CRiBiS database - universal register

Financing of assets of medium-sized enterprises with long-term debt is carried out to a greater extent. Nevertheless, the mean value of the dispersion of their long-term debt is 7 to 8 percentage points. In this group of enterprises, too, asset financing is mostly secured without credit sources. However, the last quarter of medium-sized enterprises declare 11% to 14% financial coverage of assets with loans. Lower credit financing means sufficiently high to extremely high financial coverage of interest. Medium-sized enterprises, like small enterprises, are not at risk of bankruptcy. Despite the higher current debt ratio, this group of enterprises ensures more optimistic debt repayment. This is a consequence of a more favorable return on equity and appropriate financing risk. The least efficient enterprises are no longer limited to generating a loss for every €1 of equity.

Overall, it can be stated that the debt indicators show mostly positive trends in both sets of companies. The positive trend was interrupted only by the Covid period. The area where more work needs to be done is related to the efficiency of business activities of small and medium-sized enterprises. Higher profitability will allow companies to repay debts faster, which can improve their reputation in the eyes of creditors. A more favorable reputation means better conditions for drawing on external resources.

The relationship between the characteristics of SME financing and the characteristics of Slovakia is summarized in Table 4. The indicators in the table determined the results of the presented analyses. The correlation is quantified based on the median values of the ratio indicators and the resulting score of government integrity and government spending.

Table 4. Correlations between corporate indebtedness and serious negative aspects of Slovakia

Indicators	Total debt	Long-term debt	VI to liabilities ratio	Debt repayment period	ROE
Small businesses					
Government integrity	-0.7397	x	0.7615	-0.1405	-0.3712
Government spending	0.5622	x	-0.5935	0.6772	-0.0637
Medium-sized enterprises					
Government integrity	-0.6997	0.7337	0.6991	-0.7190	0.3283
Government spending	0.2616	-0.0976	-0.2854	0.4507	-0.5685

Source: Own processing

Negative correlations prevail between the indicators. Mostly, these are medium-strong correlations. An extra strong relationship is not identified. When government integrity has a worse rating, the total indebtedness of both small and medium-sized enterprises increases. Corruption, bribery, uncertainty and pressure in economic relations increase the debt financing of corporate assets. Growing corruption further prolongs the repayment of debts, especially of medium-sized enterprises. On the contrary, a higher score of government integrity allows for more extensive financing of medium-sized enterprises with long-term debts. A positive medium-strong relationship is also quantified between government integrity and the ratio of VI to liabilities. Fewer negative interventions in the economy improve the ratio of own resources to foreign resources. Better managed government spending also increases the indebtedness of small enterprises, but the intensity of this relationship is milder. A better structure and lower volume of government spending reduce the ratio of VI to liabilities in the group of small enterprises. It seems that small businesses are willing to hold a smaller reserve of own resources to finance their needs in the given situation. In the group of medium-sized businesses, this relationship turned out to be weak. When the government spending score is more favorable, the current debt of both small and medium-sized businesses increases at the same time. Such a relationship can most likely be expected if businesses have a low level of profitability. Lower government consumption supports economic growth and improves the government's rating. Businesses expand their activities, while at the same time preferring debt financing, which is cost-effective based on the government's positive rating. Low profitability combined with greater debt financing translates into longer debt maturity. Large cuts in government spending can negatively affect the ROE of medium-sized businesses, especially those with the aforementioned low profitability. Cuts in financial support for the growth of corporate economies can ultimately be painful.

4. Discussion

Business is a continuous, time-consuming activity, the result of which depends on a number of factors. An entrepreneur can only have some of them fully under his own control. Business activities, in particular, cannot be implemented in the long term without an appropriate mix of financial resources. The owner's wealth is significantly contributed to by the ability of his business to continuously increase its own sources of financing. The owner can achieve greater success if he can communicate properly with his employees, if he knows how to improve his internal capacities and, of course, under no circumstances should he ignore the situation in the external environment. The condition of the external environment in this article is approximated by analyses of Slovakia's multi-criteria results. In the latest edition of the IMD World Competitiveness Yearbook, Slovakia's ratings are not even half the level of the best countries in all respects. Slovakia's resulting score is 46.9 (out of a maximum of 100) and the Czech Republic's 70.2. Slovakia's overall rating based on the Index of Economic Freedom is slightly more favorable. Slovakia has long been included among countries with moderate economic freedom. The biggest weaknesses of Slovakia are government spending and government integrity. These weaknesses are so great that in this respect we are assessed as a country with prevailing unfreedom, or even suppressing freedom. It turns out that both presented approaches to assessing Slovakia agree in identifying our weakest aspects, which relate to the way of governance and public finances. It can be stated that these are serious obstacles to successful entrepreneurship. The results of our country have become an impetus for the analysis of the indebtedness of small and medium-sized enterprises. The volatility of the indebtedness of small enterprises is much higher compared to medium-sized enterprises. Small enterprises are usually less indebted than medium-sized enterprises. Their typical debt gradually decreased over the period under review, from a peak of around 51% in 2017 to around 42% in 2023. The upper quartile of total debt is, on the contrary, very high, even higher than in the group of medium-sized enterprises. The vast majority of debts have a short maturity and loans are not commonly included in the debt portfolio. The median debt maturity of between around 8 and 11 years is disproportionately long given the lower current debt of small enterprises. This is most likely a consequence of the weaker profitability of this group of enterprises, as indicated by the ROE. Small enterprises have been significantly affected by the Covid period. The situation is gradually improving, but not at the necessary pace. Nevertheless, it seems that small enterprises are not at a dramatic risk of bankruptcy, thanks to self-financing. The higher current debt of medium-sized enterprises is still in line with vertical financing rules. Among the debts of medium-sized enterprises, compared to small enterprises, there are more debts with long maturities, loans are also represented, and all debts are repaid somewhat faster due to more favorable profitability. Although medium-sized enterprises are less self-financed, they are not very threatened with bankruptcy. The relationships between the indicators of corporate indebtedness and the negative characteristics of Slovakia are moderately strong and mostly negative. An extra strong relationship was not found, because the financing of enterprises is associated with a much larger group of determinants. In addition, it should be noted that the contribution presents indicators of enterprises sorted by turnover, but not by the nature of activity.

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Artificial intelligence in cost management

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Abstract: This article is devoted to explaining the relationship between artificial intelligence (AI) and cost management in a company. The work is based on a search of scientific articles and contributions by experts in the practical application of artificial intelligence. The integration of artificial intelligence into cost management procedures represents a significant development in the financial strategy and operational efficiency of companies. Artificial intelligence shows how machine learning, natural language processing and predictive analytics bring changes in budgeting, forecasting, procurement and resource allocation. Artificial intelligence helps in data-based decision-making and thus enables increased financial efficiency. By using tools (machine learning, natural language processing and robotic process automation), companies can manage costs with greater accuracy, speed and predictability. Artificial intelligence can improve traditional management functions (budgeting, cost management, costing), but also enables predictive knowledge and real-time decision-making, thereby transforming the role of financial managers.

Keywords: artificial intelligence (AI); cost management; decision making in real time; predictive analysis

Introduction

Cost management is a key part of an organizational strategy that aims to plan, track, control and reduce costs, ensuring optimal resource utilization while maximizing value. Cost management, which traditionally relied on manual processes, historical data and retrospective reporting, has undergone a significant transformation with the advent of artificial intelligence. Cost management is becoming increasingly automated, intelligent and proactive. Artificial intelligence technologies enable automation, real-time analysis and predictive capabilities, offering unprecedented accuracy and responsiveness in the management of financial resources. Cost management is therefore becoming increasingly automated, intelligent and proactive. Artificial intelligence brings new opportunities to refine expense tracking, optimize procurement and forecast financial results with greater accuracy and efficiency.

Artificial intelligence (AI) in cost management uses the following basic elements: Machine Learning (ML), Natural Language Processing (NLP), Predictive and Prescriptive Analytics, and Robotic Process Automation (RPA).

Machine learning models analyze large amounts of historical cost data to uncover patterns in cost trends and predict future spending. This allows them to predict cost behavior and optimize future budgets. These systems are trained over time, increasing the accuracy of their outputs. Supervised learning can be used to predict costs, while unsupervised learning helps identify variances or inefficiencies in spending.

Natural language processing enables artificial intelligence systems to process unstructured financial documents such as invoices, contracts, and procurement records, among others. By automatically extracting relevant information, natural language processing tools streamline document analysis, reduce manual effort, and identify document anomalies and inaccuracies.

AI-driven predictive analytics evaluates variables that influence costs, including market trends, supplier performance, and operational dynamics. These tools support scenario analysis and budgeting with high accuracy. While predictive analytics estimates future costs based on current and past trends, prescriptive analytics goes a step further and recommends actions that could improve cost outcomes. These tools simulate multiple scenarios to guide strategic financial decisions.

Robotic process automation complements artificial intelligence by automating routine cost management tasks. It is used to handle repetitive administrative tasks such as verifying invoices, processing payments, and updating ledgers, generating reports, leading to increased efficiency and reduced human error. When integrated with artificial intelligence, robotic process automation can adapt to changing inputs and handle exceptions more efficiently.

1. Literature Review

Cost management is based on Porter's value chain model. The task is to monitor the creation of value at each level of the company's activities. The quality level of the value chain is determined by the cost efficiency at each level of activity. Measuring efficiency must be precise and targeted. This creates potential for the use of Artificial Intelligence. Artificial intelligence includes the following elements: machine learning (ML), natural language processing (NLP), and robotic process automation (RPA). These elements provide data analysis, predictive modeling, and process automation. Large data sets are a source for improving decision-making in cost management. At the same time, they allow identifying recurring patterns of value creation and cost consumption (Brynjolfsson & Mcafee, 2017).

AI-driven cost analysis improves on traditional cost analysis through advanced data analysis. Machine learning algorithms can predict cost behavior with greater accuracy than traditional statistical methods. These algorithms analyze historical data to identify trends and anomalies, facilitating proactive cost management strategies. For example, machine learning models can predict cost fluctuations and optimize procurement strategies to mitigate risks associated with price volatility (Jobin &, Ienca & Vayena, 2019).

Robotic Process Automation (RPA) is another application of artificial intelligence that is significantly impacting cost management. Robotic Process Automation can automate routine, repetitive tasks such as invoice processing and financial reporting, thereby reducing labor costs and minimizing human error (Costa & S. Mamede & Mira da Silva, 2022). Empirical evidence suggests that businesses implementing Robotic Process Automation into their cost management achieve cost reductions and operational efficiencies.

Predictive and prescriptive analytics in cost management are based on artificial intelligence, enabling businesses to anticipate future costs and make informed strategic decisions. Predictive models can predict factors affecting costs and outcomes with greater accuracy, allowing businesses to allocate resources more effectively. In addition, prescriptive analytics, which recommends specific actions based on predictive insights, is gaining popularity (Yusuf et all, 2024). Prescriptive analytics can optimize resource allocation, increase budgeting accuracy, and streamline supply chain operations.

As Artificial intelligence in finance continues to enter its adoption and growth phase, its full benefits and potential threats are expected to become more apparent over time. This dynamic has fueled a significant increase in publications on AI in finance in recent years, as researchers seek to address gaps in the literature and identify emerging trajectories for the field (Goodell et al., 2023).

The future of work will be influenced and transformed by AI and other socio-technological forces, and AI is unlikely to cause massive, net loss of professional jobs (Sarala et al. 2025). Rather, professions, which have a long history of shielding themselves from contextual shocks, will reconfigure their skills, innovate to compensate for threats, and reassess the boundaries of their work to expand and protect their competencies. These changes seem inevitable because of interdependencies: changes in any organizational process are likely to trigger adaptations in other processes, accelerating the way firms address AI threats; the use of abstract knowledge driven by AI will require more relational expertise; bottom-up demands on firms will need to be met through top-down strategies focused on skills acquisition and training and innovation, driving changes in internal and external mobility trajectories.

Deep learning has emerged as a powerful tool for predicting merger and acquisition targets. It has revolutionized the way companies identify potential acquisition targets. Traditional valuation methods rely on financial metrics and historical performance, but deep learning algorithms can process vast amounts of unstructured data, including news articles, social media sentiment, and market trends (Karatas & Hirsa, 2025). By leveraging this wealth of information, deep learning models increase the accuracy of target identification and evaluation. These models can uncover underlying patterns and relationships that traditional methods may miss, offering new insights and perspectives.

Deep learning algorithms have demonstrated effectiveness in detecting and quantifying mispricing in the stock market, providing a reliable metric for assessing the extent of mispricing in a diffuse market environment (Tang, 2025). Deep learning models can be valuable tools for predicting potential mergers and acquisitions targets by analyzing patterns and anomalies in stock market mispricing. This potentially helps firms identify attractive acquisition opportunities. The mood of market participants is a significant factor, and incorporating sentiment analysis through deep learning models increases the accuracy of mispricing detection, thereby influencing mergers and acquisitions activities.

2. Methodology

The topic of the article is Artificial Intelligence and Cost management. The aim of this article is to clarify the mutual relationship between Artificial Intelligence and Cost management. To achieve this goal, we have chosen the method of literature reviews, source research and searching for relevant literature.

We searched for literature from freely available scientific journals, through the Slovak Economic Library and its electronic databases. The result of the Internet search is a selection of relevant sources that we have studied. These sources are listed in References. We mainly selected scientific articles, in order to obtain basic knowledge, in accordance with the topic of our research.

3. Results

Integrating Artificial Intelligence into cost management, despite its advantages, presents various challenges and ethical aspects. Privacy must be ensured, and data security is paramount (Vuković & Dekpo-Adza & Matović, 2025). The ethical implications of using AI, such as bias in decision-making and the dismissal of human workers, need to be carefully considered and decisions made seriously.

According to the 2023 Gartner, Inc. (Gartner, Inc., 2024) Finance Leaders Survey of 133 finance leaders, sixty-eight percent of finance organizations are using artificial intelligence and machine learning or plan to use the technology.

Gartner has identified three characteristics of today's most successful finance organizations using Artificial Intelligence:

1. Short-term results are possible, but transformational results take time. While short-term benefits from AI are possible through simple to complex solutions, the transformational value of AI in finance requires a level of maturity that takes time to build.
2. Data science is emerging as a new role in finance. The majority of finance teams report using data scientists. Modern finance teams routinely use data scientists, whether they use AI or not.
3. Adoption plays a role in AI success. Organizations with high levels of AI adoption report high success rates. Without the support of informed process owners, creating AI-driven processes that mimic their decisions and actions proves difficult.

There are three phases of analytics (Lepenioti et al. 2020):

Phase 1: Descriptive analytics, which aims to help decision makers understand what happened in the past and why it happened.

Phase 2: Predictive analytics, which aims to predict what will happen in the future and why it will happen.

Phase 3: Prescriptive analytics, which aims to prescribe what actions should be taken and why they should be taken.

AI-driven cost management decision support tools help managers evaluate cost scenarios and make strategic decisions (Csaszar & Harsh & Kim, 2024). These systems integrate various AI technologies. This provides a comprehensive overview of the cost structure and the potential impact of various strategic decisions. AI-driven cost management can simulate different pricing strategies and their impact on profitability, enabling decision-making based on a large set of data.

We will also see the emergence of new professional groups around new technologies and their application to specific professional tasks, but these are likely to operate in increasingly dense patterns of relationships with existing professions. So rather than a simple story where new groups replace old ones, we have the creation of increasingly complex networks of collaboration through which, in particular, expert services are jointly produced. However, the implications may also extend beyond the boundaries of individual organizations. Faulconbridge et al. (2023) suggest that the growing importance of Artificial Intelligence for professional services firms will potentially disrupt existing power dynamics within these firms by empowering those with the skills to design and operate these increasingly sophisticated systems. This is important because the governance mechanisms of these firms have traditionally been organized around partnership structures with key positions restricted to qualified members of their core profession. The growing importance of artificial intelligence could further strain these mechanisms, as firms will need to find ways to rethink existing governance structures to reward and position technologists and new hybrid professionals in leadership positions.

4. Discussion and conclusion

The real use of Artificial Intelligence requires experience in data analysis, query formulation, setting relationships between variables, a sufficient size of the database, but also experience with modern analytical tools, reporting, logic, and assessing the objectivity of recommendations. Applying artificial intelligence to cost management requires, for example:

- dynamic budgeting and real-time forecasting. Artificial intelligence improves financial planning by generating ongoing forecasts that are updated in real time as new data becomes available. Artificial intelligence improves budgeting processes by providing data-driven forecasts that adapt to market conditions and historical trends. Adaptive forecasting models dynamically respond to real-time inputs, improving not only planning accuracy but also responsiveness in budget control.
- procurement optimization. Artificial intelligence identifies optimal suppliers, analyzes supplier performance, price negotiations, and monitors market prices to minimize procurement costs. It creates demand forecasts so that businesses can make cost-effective purchasing decisions. Cognitive procurement tools also analyze supplier risk, past performance, and regulatory compliance. These systems help reduce procurement fraud and improve contract compliance.
- resource efficiency and allocation. Artificial intelligence supports optimal resource allocation by evaluating project timelines, labor costs, and material requirements. It suggests optimizations to minimize waste and costs while maintaining productivity. This is particularly valuable in industries such as construction, manufacturing, and logistics.
- fraud detection and risk mitigation. Artificial intelligence systems can flag unusual spending behavior or fraudulent transactions by monitoring cost flows and comparing them to predictive norms. By continuously monitoring transaction patterns and comparing them to learned norms, they reduce the risk of financial losses.
- automated financial reporting and analytics. Artificial intelligence simplifies reporting by aggregating data from multiple systems, creating detailed dashboards, and providing insights from large data sets that inform management decisions, all with minimal human intervention. This increases transparency and speed of decision-making.

The challenges and aspects of Artificial Intelligence implementation also require addressing the following issues and problems:

- data availability, quality, completeness, standardization and integration. The performance of Artificial Intelligence is directly related to the quality and consistency of input data. Many businesses face difficulties integrating data from diverse and fragmented sources. Inconsistent data formats and isolated information systems pose significant obstacles.
- compliance with regulations, regulatory and ethical issues. The use of Artificial Intelligence in financial decision-making must comply with ethical standards and financial regulations. Transparency, accountability and explainability of Artificial Intelligence decisions remain key challenges to ensure its responsible deployment.
- organizational readiness and workforce adaptation. Adoption of Artificial Intelligence requires changes in organizational culture, employee mindsets, technical upskilling of employees and alignment of corporate culture with digital innovations. Resistance to automation and fear of job losses are common obstacles.
- initial investment for implementation. Although Artificial Intelligence offers long-term savings, the initial implementation costs, including infrastructure, training, and customization for deployment and maintenance, can be high, especially for small and medium-sized businesses.

Artificial intelligence is redefining the field of cost management by enabling smarter, faster, and more accurate financial and cost-effective decisions. Artificial intelligence will not only be a tool for automating routine tasks, but also a strategic asset for transforming the way businesses manage costs. From automating repetitive tasks to predicting complex financial scenarios, Artificial intelligence tools are proving essential for achieving cost efficiency and operational optimization. By improving data visibility, predictive capabilities, and operational efficiency, Artificial intelligence will enable decision makers to drive cost-saving strategies with greater confidence and accuracy. However, the successful use of Artificial intelligence tools will depend on addressing data management challenges, industry specifics, technical challenges, ethical use, and the readiness of businesses to transition to a new way of managing.

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The benefits of a circular economy

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Abstract: The circular economy is based on using available resources in an environmentally and economically sustainable way. Unlike traditional linear growth, the circular economy involves minimising waste and limiting resource inputs. As a result, the circular economy concept is intended to protect the environment and reduce our dependence on natural resources. The article focuses on legislation, principles of circular economy, benefits and trends in circular economy

Keywords: circular economylegislation, principles of circular economy, benefits of circular economy, models of circular economy.

Introduction

The Circular Economy (CE) is a systemic approach to economic development that aims to minimize waste, optimize the use of resources and close material flows to prevent waste. In contrast to the traditional linear model of "extract - produce - consume - dispose", CE seeks to keep products, components and materials in circulation for as long as possible.

1. The Circular Economy (CE)

The circular economy (CE), or also the circular economy, brings many challenges and opportunities to the business world. The economic model of today's society is so far primarily linear. We extract natural resources, take them to the other end of the world where they are made into products. These are distributed to other parts of the world, where consumers buy them, use them and throw them away. This creates waste and the raw materials in the form of products end up in landfills, incinerators or strewn in the wild.

Basic principles of the circular economy

The concept of circular economy was developed in response to the current linear nature of material flows. Primary raw materials such as oil, metals or trees are extracted, converted into products, and end up in landfills or incinerators once their life cycle is over. The situation is also exacerbated by the fact that up to 95% of products end their life cycle after just 6 months of purchase.(1)

The circular economy, which combats this very trend, is often defined as a zero-waste concept. Following the model of natural ecosystems, it proposes closing the flows of materials in functional and never-ending cycles, dr)awing energy from renewable and sustainable sources, and creating sustainable products and services.(7)

Figure 1: The principle of circular economy and material flows
Source: Inštitút cirkulárnej ekonomiky (incien.org)

The main features of this model are the use of renewable energy, renting, sharing, support for local trade, eco-innovation or eco-design. Priority in the circular system is given to products with a long lifetime and used in the long term. They are seen and designed as repositories of raw materials. Easy disassembly is key, allowing the separation of individual components or materials and their subsequent recovery. The result is the elimination of waste that can no longer be used (1).

The circular economy is an economic system in which products are designed to last as long as possible in the economy, through design that allows products to be repaired, reused and materials easily separated for recycling. Customers do not have to own the products, but can borrow or share them. The circular economy is guided by 3 principles:

- eliminate waste and pollution,
- circulate products and materials (at their highest value),
- ◎ ◎ regenerate nature.

Compliance with the above principles shall be taken into account in any change to processes within the circular economy. The transition from a linear economy (where products and materials are thrown away after use) to a circular economy represents a systemic change that requires comprehensive, conceptual changes in business management as well.(10)

2. Methodology

The main objective of the scientific article is to highlight the circular economy, to point out the principles of the circular economy.

In the scientific article general research methods were used.

The subject of investigation is the tools of circular economy, EU legislation to ensure the promotion of circular economy, implementation steps of circular waste management application, advantages of implementing circular economy in the enterprise.

3. Results

3.1. EU legislative framework supporting CE

The European Union plays a key role in promoting the circular economy through legislative and financial instruments. The most relevant are listed in Table 1.

CE LEGISLATIVE AND FINANCIAL INSTRUMENTS	Characteristics and main focus
Circular Economy Action Plan (2020, part of the European Green Deal)	• ecodesign of products (durability, repairability), • the consumer's right to repair, • the obligation for producers to be responsible for the entire life cycle of products, • the promotion of circular business models.
Ecodesign Regulation for Sustainable Products (ESPR, draft 2022 adopted July 2024)	• aims to increase the circularity, energy efficiency and recyclability of products on the EU market
EU Taxonomy for Sustainable Financing	• enables the identification and promotion of 'green investments', including CE projects, thereby creating better access to finance for companies engaging in the circular economy.
New framework for Extended Producer Responsibility (EPR)	• reinforces the responsibility of producers to collect, reuse and recycle products at the end of their life • Extended Producer Responsibility (EPR) is a policy instrument that extends the financial and/or operational responsibility of the producer for the product (11)

Table 1. Relevant CE legislative and financial instruments
Source: europen-packaging.eu

Circular Economy Action Plan (2020)

This plan is part of the European Green Deal and the objectives emphasise. The measures that will be introduced under the new action plan aim to (4):

- make sustainable products the norm in the EU
- empowering consumers and public procurers
- focus on the most resource-intensive sectors with high circular economy potential, such as: electronics and ICT, batteries and vehicles, packaging, plastics, textiles, construction and buildings, food, water and nutrients
- to ensure less waste
- making circularity work for people, regions and cities
- lead global efforts on circular economy

Ecodesign Regulation for Sustainable Products (ESPR)

It introduces the obligation of digital product passports, which allow tracking of material composition and increase transparency in supply chains. Takes circular criteria into account in public procurement processes. Establishes performance requirements and product information. The 2025-2030 Work Plan then selects the products to be prioritised for eco-design requirements under the ESPR and energy labelling under the ELFR and defines practical requirements for products prioritised under the ESPR.

EU Taxonomy for Sustainable Financing

Proof that the circular economy is a priority for the EU and an important tool for achieving climate neutrality by 2050 is the fact that the transition to a circular economy is one of the environmental objectives of the EU Taxonomy Regulation and businesses will have to report on how their economic activities help or "significantly harm" this objective.

These legislative changes naturally set trends in the circular economy and present both challenges and opportunities for businesses.

IMPLEMENTATION STEPS	Main activities - measures
Waste prevention	• do not waste material • optimise product design to avoid waste at any stage of the product life cycle
Sorting waste into recyclable components	• Proper sorting and storage is an essential step as it reflects on the final value of the waste • digital waste marketplace
Ensuring closed cycles in the enterprise	• return of material back to production within the plant
Odpredaj odpadu na ďalšie využitie či recykláciu	• Finding a suitable buyer for waste (e.g. advertising portals such as Cyrkl - Digital Waste Marketplace)
Use of secondary raw materials in production	• available recyclates can be a cheaper input material, often matching the quality of virgin raw materials
Knowledge of the exact composition of products and assurance of recyclability	• analyse and adjust product composition to make it sustainable

Table 2: Implementation steps for the application of circular waste management

Source: Own processing by waste - postal.sk

The implementation of circular economy (CE) principles faces a number of market constraints that hinder its wider diffusion in business practice (3):

- Economic barriers
- Insufficient demand
- Institutional and regulatory constraints
- Technological and logistical challenges
- Market rigidities and risks

Economic barriers

High upfront investment in recycling, design and digitalisation technologies. Longer return on investment (ROI) in circular models compared to linear approach. Low primary raw material prices reduce the incentive to use recyclates. External costs (e.g. environmental damage) are not included in the market price of products.

Insufficient demand

Low consumer willingness to pay more for sustainable or recycled products. Poor market awareness of the benefits of circular solutions. Misleading labelling ("greenwashing") hinders trust in CE products.

Institutional and regulatory limits

Lack of incentives and subsidies for circular enterprises compared to traditional industry. Complex and inconsistent legislative frameworks (e.g. for waste vs. secondary raw material transport). Non-existent standards for the quality of recycled materials or circular products.

Technological and logistical problems

Low availability of technologies for separation and recycling of complex materials. Fragmented supply chains that make reverse flows of materials difficult. Lack of infrastructure for collection, sorting and treatment of waste.

Market rigidities and risks

Resistance to changing business models (e.g. from sale to rental). Fear of loss of competitiveness, especially when exporting to countries without CE requirements.

Market volatility of recycled raw materials (volatile prices, availability). These constraints require systemic solutions - from legislative reforms, to public investment, to consumer education.

3.2 Circulating business models

There are many circular business models that companies can apply to meet legislative requirements and at the same time increase their competitiveness.

Biznis model	Focus
Product Life Extension	• focuses on repair, refurbishment, remanufacturing and modernization of products • example: laptop manufacturers who offer refurbished models with a new warranty.
Closed-Loop Systems	• materials and components from discarded products are reused in new products. • example: carpet manufacturers who take back old carpets and make new ones from recycled material.
Sharing Platforms	• maximises product utilisation by being shared by multiple users • example: carsharing, bikesharing, shared workshops or tools
Resource Recovery	• aimed at recovering by-products, waste or emissions as a new resource. • example: a company that produces biogas or compost from food waste
Product-as-a-Service	• the customer pays for the use of the product, not for its ownership. • the manufacturer is motivated for longer life and easy maintenance
Circular Design	• products are designed from the outset to be easily repairable, degradable, recyclable and made from renewable or secondary raw materials. • example: Modulárne smartfóny ako Fairphone

Table3: Circulating business models
Source: Own processing by waste - postal.sk

The benefits of the circular economy for businesses

BENEFITS	Characteristics
Reduction of input costs	• using recycled materials • refurbishing products • reuse in the production process
New sources of profit	• circular solutions can create new markets • innovation in the textile industry
Reducing the risk associated with fluctuations in raw material prices	• by taking back products, the need for extracting new raw materials can be reduced, the supply of material can be kept stable and thus the price of material can be kept stable • by using recycled materials
Positive green corporate image	• CiE principles can reduce the environmental footprint of products and thus differentiate them from competitors • the green image of your product can be communicated externally through the "Environmentally Friendly Product" label • other supporting tools to improve the company's image include EMAS or green procurement
Incentive to innovate	• the principles of the circular economy open up opportunities for increasing the efficiency of a company's resources, bringing a new perspective to the business model and thus stimulating innovation

Table 4: Circulating business models
Source: Own processing

While CE offers significant benefits, its implementation faces a number of challenges:

- Lack of standardization and legislation.
- Technological barriers to recycling complex materials.
- Consumer habits and low awareness.
- Need for new business models and incentives for businesses.

4. Discussion

The circular economy is based on using available resources in an environmentally and economically sustainable way. Unlike traditional linear growth, which is based on a 'take, make, throw away' model, the circular economy involves minimising waste and limiting resource inputs. The concept of the circular economy is thus intended to ultimately protect the environment and reduce our dependence on natural resources. In order to achieve this ambitious goal, a responsible approach by both producers and consumers to all the integral processes of a product's lifecycle, i.e. design, production, consumption and recycling, is essential.

To achieve a green economy requires cooperation between government, business, civil society and academia. Creating legislation and policies that promote green solutions and stimulating the market for green products and services are essential.

5. Conclusion

In this paper, we have tried to highlight the principles of circular economy, implementation of circular economy and benefits of circular economy.

The circular economy is a response to the growing societal pressure for a more sustainable and equitable economic model. However, its development is conditional on the ability to overcome the economic, technological and regulatory barriers of the current market environment. The transition to CE requires a coordinated approach between all stakeholders, including the public sector, business, research and civil society.

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The hydropower potential and its use in Slovakia

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Abstract: From an environmental point of view, hydropower has a much lower carbon footprint than fossil fuels, but it can also cause interference with natural ecosystems, fish migration, bank erosion, microclimate changes and water level fluctuations. These factors require a thorough environmental analysis and compensation measures. From the point of view of hydropower, Slovakia has an advantageous geographical and hydrological location. Slovakia still has some untapped hydropower potential, especially in the area of small hydropower plants and the modernization of existing facilities. The aim of the article is to familiarize the reader with the importance and use of hydropower potential in Slovakia. The article presents several sources of use of Slovak watercourses for the production of electricity from renewable sources. The article also defines the current and future usable potential of Slovak rivers in the field of hydropower, as well as the factors that largely influence and limit it.

Keywords: hydropower potential; renewable energy sources; hydroelectric power plants

Introduction

Hydropower represents the ability of watercourses and their energy gradient to produce mechanical energy, which can subsequently be converted into electrical energy through hydropower facilities, most often hydroelectric power plants. Hydropower is one of the main representatives of renewable energy sources, mainly due to its availability, stability and relatively low environmental impact compared to fossil fuels. The Slovak Republic, as a landlocked country with a significant proportion of mountainous territory and a relatively dense hydrographic network, has significant hydropower potential on its territory, which has already been identified and used to a large extent.

1. Theoretical background

Hydropower potential can be divided into three main categories:

Theoretical hydropower potential expresses the maximum possible amount of energy that could be obtained from the watercourses of a given area if all flows and gradients were fully utilized without any technical, economic or environmental limitations. In the case of Slovakia, the theoretical hydropower potential is estimated at approximately 12,000 GWh/year.

Technically usable hydropower potential takes into account the possibilities of constructing hydroelectric power plants in suitable locations with regard to actual flows, gradients, accessibility of the area, geological conditions, distance from the distribution network and other factors. In the Slovak Republic, this value is around 6,600 GWh/year, which represents approximately half of the theoretical potential.

Economically and **ecologically utilized hydropower potential** represents the part of the potential that is actually utilized under current price and environmental conditions. Currently, approximately 4,500 GWh/year is used in Slovakia, which constitutes a significant part of electricity production from renewable sources, specifically around 15% of total electricity production.

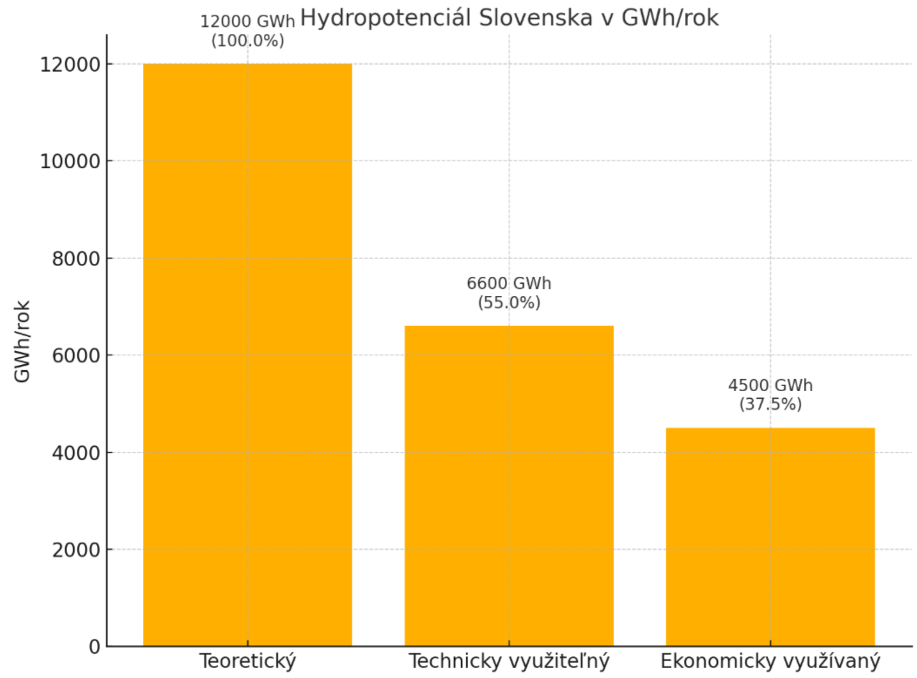

Chart 1 Hydro potential of Slovakia in GWh/year

Source: own processing

2. Methods and methodology

The aim of the article is to familiarize the reader with the importance and use of hydropower in Slovakia. The article presents several sources of use of Slovak watercourses for the production of electricity from renewable sources. The article also defines the current and future usable potential of Slovak rivers in the field of hydropower, as well as the factors that significantly influence and limit it.

3. Results

From the point of view of hydropower, Slovakia has an advantageous geographical and hydrological position. Most of the territory lies in mountainous and foothill areas (e.g. the Western, Central and Eastern Carpathians), where there is naturally a higher elevation difference (slope) and shorter, but steeper river flows. These conditions are ideal for the construction of hydropower facilities. The main rivers that form the backbone of the hydropower system are the Danube, Váh, Hron, Orava, Hornád, Poprad and Slaná. The most important role is played by the Váh River, which has built the so-called Váh cascade - a set of connected dams and power plants that ensure uniform electricity production and flow regulation.

Hydrologically, Slovakia belongs to the Danube River basin, which is the most important river in this part of Europe and also forms part of the country's southern border. Slovakia also has significant groundwater reserves. In the Danube Lowland there are extensive layers of groundwater that serve to supply drinking water to large cities and industrial areas. The most important water reservoirs include the Orava Dam, Liptovská Mara and Zemplínska Šírava, which serve not only to supply drinking water, but also to produce electricity, for recreation and flood protection.

Annual precipitation in Slovakia varies greatly depending on altitude and terrain exposure. In high-mountain areas, precipitation is higher and runoff is more intense. During the spring and summer months, mountain areas can experience flash floods due to sudden and heavy rains. Slovakia is divided into three main river basins: the Danube basin forms a large part, and the Váh, Hron and Morava basins are also significant. The river network is dense, with mountain streams responding quickly and sharply to precipitation, which is important for the use of hydropower and at the same time requires good flood control measures.

The overall hydrological and geographical conditions of Slovakia create diverse opportunities for the use of water resources. The mountainous relief with many rivers and springs provides good potential for hydropower, while the lowland areas are important for agriculture and water supply for the population. Given the differences in the distribution of precipitation and runoff, it is necessary to have an effective network of dams and flood protection measures.

Climate change has a significant impact on the hydrological situation in Slovakia, which means that it changes the quantity, distribution and quality of water resources in the country. In recent decades, Slovakia, like the rest of Central Europe, has seen a tendency towards an increase in average temperatures, which affect the water cycle in nature. Higher temperatures cause more intense evaporation of water from the soil, rivers, lakes and vegetation, which can reduce the availability of surface and groundwater, especially in the summer months. At the same time, the distribution of precipitation throughout the year is also changing - fluctuations between dry periods and, conversely, heavy rains, which can cause flash floods, are more frequent. These extremes put a strain on aquatic ecosystems and infrastructure, such as dams, dykes and sewers.

Another problem is the change in snow cover in high mountain areas. Snow is a natural reservoir of water that is gradually released during spring and early summer, thus maintaining river flows and supplying water reservoirs. However, if temperatures rise and snow melts faster or forms less in winter, the period of slow water release is shortened. The result can be higher river levels during spring, which can cause floods, and subsequently water shortages in summer and autumn, which threaten agricultural production, population supply and hydroelectric power generation.

Climate change also affects water quality. More frequent, intense rains can increase the runoff of nutrients and pollutants into rivers and lakes, leading to pollution and worsening conditions for aquatic life and human water use.

In summary, climate change in Slovakia is causing greater variability and extremes in the hydrological cycle - more frequent droughts, severe floods, changes in the quantity and quality of water, which places demanding requirements on water resource management, infrastructure adaptation, and sustainable water management.

3.1 Main hydropower facilities in Slovakia

There are several dozen hydroelectric power plants in Slovakia, which are divided according to their capacity into large, small and micro hydroelectric power plants.

The most important and largest hydroelectric power plant in Slovakia is **the Gabčíkovo Hydropower Plant** on the Danube. This plant is part of the Gabčíkovo-Nagymaros system and is of fundamental importance for electricity generation, Danube level regulation, water supply, navigation and flood protection. The Gabčíkovo power plant has an installed capacity of approximately 720 MW, which makes it one of the largest hydroelectric power plants in Central Europe. It is capable of producing around 2.7 to 3 billion kilowatt hours of electricity annually. It consists of a dam, a navigation channel and a hydroelectric power plant. This plant significantly contributes to Slovakia's energy self-sufficiency, while also fulfilling important flood control and environmental functions.

Another important waterworks is **the Žilina Waterworks** on the Váh River, which serves as a water reservoir, but also for electricity production, with the hydroelectric power plant having an installed capacity of approximately 25 MW. Its importance lies in stabilizing the water regime of the Váh, which helps regulate floods and provides water for energy and industry. There are several smaller hydroelectric power plants on the Váh, which together form a significant hydro potential of this river. Among the well-known ones are the **Krásno nad Kysucou, Liptovská Mara** and **Čierny Váh** hydroelectric power plants.

The Liptovská Mara hydroelectric power plant is also a large reservoir, which, in addition to hydropower, also serves for flood protection and recreation. It was created by building a dam and is one of the largest hydroelectric power plants in the country. The installed capacity of the Liptovská Mara hydroelectric power plant is approximately 36 MW, and its main tasks include, in addition to electricity production, water supply, flow regulation, flood protection and recreational use. There are several smaller hydroelectric power plants on the Hron River that use local water potential, for example in the Banská Bystrica and Podbrezová areas.

In addition to large and medium-sized hydroelectric power plants, there are also a number of small hydroelectric power plants (SHPs), which are mainly located in the mountainous and foothill areas of Slovakia. These small facilities often use local river and stream flows and contribute to local energy self-sufficiency.

Overall, hydropower in Slovakia takes advantage of the diversity of the landscape, where mountain streams and rivers with steep gradients provide suitable conditions for the production of electricity from renewable sources. However, the country's hydropower potential is limited by the relatively small distribution of large watercourses, which is why it is often combined with other energy sources.

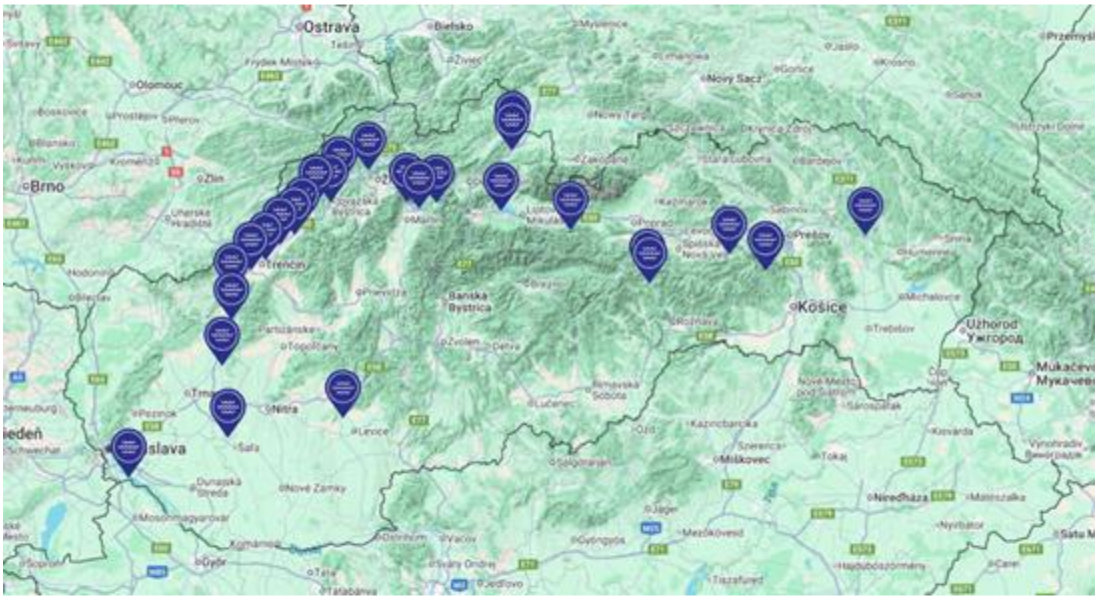

Figure 1 The map of Slovak hydroelectric power plants

Source: https://www.seas.sk/o-nas/nase-elektrarne/mapa-elektrarni/

3.2 The Small hydropower plants (SHP)

Small hydropower plants (up to 10 MW) represent a flexible and less invasive form of utilizing hydropower potential, especially in mountainous and foothill areas. There are over 250 of them in operation in Slovakia. The advantage of SHP is the possibility of decentralized energy production, reduced transmission losses and less intervention in the landscape. However, in terms of environmental impact, they require sensitive assessment and regulation, especially with regard to interference with fish migration routes, sedimentation and changes in the hydrological regime of streams. These power plants are often located on mountain streams, creeks and smaller rivers. Their main advantage is a quick return on investment, environmental friendliness and the possibility of decentralized electricity production. Small hydropower plants contribute to supplementing the energy mix and support regional development.

3.3 Economic and environmental aspects of using hydro potential

From an economic perspective, hydroelectric power generation is stable, predictable and has low operating costs once construction is complete. However, construction can be costly and time-consuming. From an environmental perspective, hydroelectric power has a much lower carbon footprint than fossil fuels, but it can also cause interference with natural ecosystems, fish migrations, bank erosion, microclimate changes and water level fluctuations. These factors require rigorous environmental analysis and compensation measures.

3.4 Perspectives and future development

Slovakia still has some untapped hydropower potential, especially in the area of small hydropower plants and the modernization of existing facilities. There is also potential in more effective linking of hydropower with energy storage (e.g. batteries, pumped storage plants) and integration with other renewable sources. Future development should be accompanied by sustainable planning, participation of local communities and strict adherence to ecological principles.

4. Discussion

Slovakia's hydropower potential represents an important pillar of the country's energy mix, significantly contributing to the production of clean and renewable energy. Slovakia has managed to use its hydropower potential to a significant extent, while in the future there is room for further sustainable development, especially in the area of small hydropower plants, modernization of existing facilities and intelligent management of water resources. The efficient and ecologically balanced use of this potential is the key to the country's energy security and environmental responsibility.

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Industry 5.0 and Sustainability in Business

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Abstract: This paper aims to explore how the principles of Industry 5.0 can support sustainable business practices in modern enterprises. The methodology is based on a qualitative research approach, combining a structured literature review with secondary data from case studies and industry reports. The main findings highlight that Industry 5.0 enables businesses to enhance operational efficiency, reduce resource consumption, and support social well-being through technologies such as collaborative robots, digital twins, and AI-driven analytics. Additionally, Industry 5.0 promotes circular economy models, strengthens workforce engagement, and improves competitive positioning. The study concludes that Industry 5.0 represents a strategic shift toward human-centric, resilient, and sustainable business models, and its successful implementation depends on organizational adaptability, technological integration, and long-term commitment to sustainable innovation.

Keywords: Industry 5.0; sustainability; digital transformation; circular economy; smart manufacturing

Introduction

Sustainability has become one of the most pressing priorities in the global business landscape, driven by climate change, regulatory demands, and increasing consumer expectations. As stakeholders call for more responsible practices, businesses are compelled to integrate environmental, social, and governance (ESG) principles into their core strategies. Within this context, Industry 5.0 emerges not only as a technological evolution but also as a response to the urgent need for sustainable development. By placing humans at the center of industrial innovation, Industry 5.0 bridges the gap between advanced technologies and sustainability goals, aligning economic growth with social well-being and environmental stewardship.

The advent of Industry 5.0 marks a significant evolution in industrial paradigms by integrating human intelligence with advanced technologies such as artificial intelligence, the Internet of Things (IoT), and robotics (Breque et al., 2021). Unlike its predecessor, Industry 4.0, which primarily focuses on efficiency through automation, Industry 5.0 emphasizes human-centricity, resilience, and sustainability (European Commission, 2021). This transformation holds particular relevance for businesses striving to meet ESG goals while navigating digital disruption. This paper aims to explore how the principles of Industry 5.0 can support sustainable business practices, contributing to both organizational performance and broader societal outcomes.

1. Literature Review

Industry 5.0 has been recognized as a framework that prioritizes collaboration between humans and machines, aiming to create a more personalized and sustainable production environment (Nahavandi, 2019). According to the European Commission (2021), Industry 5.0 extends the concept of digital transformation by integrating social and environmental dimensions into technological advancement. Sustainable business practices, particularly those grounded in the circular economy, benefit from such integration as it promotes responsible resource use, waste reduction, and social well-being (Geissdoerfer et al., 2017).

In this context, Bousdekis et al. (2021) highlight that the move to Industry 5.0 necessitates a redesign of performance management systems to include environmental and social metrics alongside traditional productivity measures. Similarly, Madsen and Madsen (2022) argue that the paradigm shift emphasizes knowledge co-creation between humans and AI systems to solve complex sustainability challenges.

The application of cyber-physical systems and smart sensors is also seen as pivotal in supporting environmentally sustainable operations (Rajput & Singh, 2019). These technologies enable real-time data collection and analysis, allowing firms to monitor their environmental footprint more accurately and respond promptly to inefficiencies.

Furthermore, Lasi et al. (2014) provide early insights into how Industry 4.0 laid the technological groundwork for Industry 5.0 by promoting integration across value chains. Their work underscores the critical need for a human-oriented evolution that leverages this infrastructure to create inclusive and ecologically responsible business models.

Many scholars have noted the progressive evolution from Industry 4.0 to Industry 5.0, emphasizing the need for a more inclusive approach to technological development. For instance, Demir et al. (2019) argue that while Industry 4.0 emphasizes productivity and connectivity, it often overlooks the societal and ethical implications of rapid automation. In contrast, Industry 5.0 introduces a framework that harmonizes technological innovation with human values and sustainability goals.

Moreover, Xu, Xu, and Li (2018) examine the transition challenges from Industry 4.0 to 5.0, highlighting the importance of organizational adaptability and strategic alignment. Their research stresses that Industry 5.0 must build on the digital foundations of Industry 4.0 while simultaneously addressing environmental and human-centric design priorities.

Zhou, Liu, and Zhou (2020) delve into the enabling technologies that support this shift, such as AI, edge computing, and human-robot collaboration. These technologies are not only reshaping production systems but also redefining labor practices and corporate responsibilities in achieving sustainability.

Recent studies indicate that companies aligning with Industry 5.0 principles are better positioned to tackle climate change and meet international sustainability targets such as the United Nations Sustainable Development Goals (SDGs) (Kamble et al., 2020). Additionally, digital twin technology, human-machine collaboration, and advanced analytics play critical roles in enabling real-time monitoring and optimization of sustainability metrics (Ivanov et al., 2020).

Current implementations of Industry 5.0 features in businesses include the deployment of collaborative robots in automotive assembly lines, which has improved both worker safety and precision in production (Demir et al., 2019). In the logistics sector, smart wearables and AR devices are used to optimize warehouse operations, resulting in reduced operational downtime and energy use. Furthermore, major electronics manufacturers have integrated digital twin technologies to simulate production environments, leading to significant material savings and reductions in carbon footprint. These implementations have demonstrated tangible benefits such as cost reduction, productivity enhancement, improved employee well-being, and more transparent supply chains.

Additionally, companies in the consumer goods sector have begun utilizing human-machine collaboration to offer hyper-personalized products at scale. For example, luxury fashion brands are employing AI-driven design platforms that incorporate consumer feedback and co-creation tools to reduce overproduction and waste. These systems enhance customer engagement and align production with demand, supporting sustainability goals.

In the food processing industry, real-time monitoring systems powered by IoT and machine learning are now being used to control energy consumption, reduce spoilage, and optimize logistics. This not only cuts operational costs but also contributes to lower greenhouse gas emissions and food waste.

Manufacturers in high-tech industries have reported that digital twin implementation has enabled closed-loop manufacturing systems—allowing data from product use and disposal phases to inform continuous design improvements. This feedback loop enhances resource efficiency and extends product lifespans, advancing circular economic objectives.

From a social perspective, smart factories embracing Industry 5.0 principles often integrate health monitoring wearables to enhance worker safety and ergonomics. As a result, these firms report fewer workplace injuries and higher employee satisfaction scores, reinforcing the concept of a human-centric industrial environment.

Moreover, companies that have embedded blockchain for sustainable sourcing verification are observing increased trust among stakeholders and consumers. By ensuring ethical procurement and full supply chain traceability, businesses can differentiate their brands and comply with international regulatory frameworks on environmental and labor standards. As more firms integrate Industry 5.0 elements into their operations, they report improved stakeholder confidence and stronger alignment with ESG standards (Bonilla et al., 2018; Saberi et al., 2019).

In summary, the literature reflects a strong consensus that Industry 5.0 represents a pivotal shift in industrial strategy—one that emphasizes human-centric and sustainable innovation. The body of research review demonstrates how organizations are beginning to implement these concepts through technologies like digital twins, cobots, and blockchain, with measurable benefits in productivity, efficiency, and environmental performance. While challenges remain, especially in terms of investment and workforce adaptation, the early evidence suggests that the transition to Industry 5.0 can serve as a powerful enabler of long-term business resilience and sustainability. As both academic and practical insights continue to evolve, Industry 5.0 is poised to become a central pillar in responsible business transformation. (Bonilla et al., 2018; Saberi et al., 2019).

2. Methodology

This study employs a qualitative research approach aimed at exploring the role of Industry 5.0 in advancing sustainability within business contexts. The methodology is primarily based on a comprehensive and systematic literature review, encompassing peer-reviewed academic articles, industry reports, and white papers related to Industry 5.0, Industry 4.0, and sustainable business practices.

The selection criteria for sources included relevance to the research topic, recency (focusing mainly on publications from the last decade), credibility of publishers and authors, and citation frequency. The literature was synthesized thematically to identify key technological components, human-centric innovations, and sustainability outcomes associated with Industry 5.0.

In addition, the study analyzed secondary data from recent industry case studies and reports to illustrate real-world implementations of Industry 5.0 features. This data included quantitative indicators such as energy consumption, waste reduction, employee satisfaction, and operational efficiencies, as well as qualitative evidence on workforce transformation and stakeholder engagement.

A thematic analysis was conducted to integrate insights from diverse data sources, focusing on how Industry 5.0 principles facilitate circular economy integration, enhance competitive advantage, and promote sustainable innovation. The findings were organized to highlight both the technological enablers and organizational changes required for successful Industry 5.0 adoption.

3. Results

This section presents the key findings from the study, highlighting how Industry 5.0 contributes to sustainability in business. Through empirical data and analysis of industry practices, we identify specific improvements in operational efficiency, environmental performance, and workforce dynamics. The results are organized into subsections to illustrate both quantitative and qualitative impacts.

Recent global analyses highlight the growing adoption of Industry 5.0 technologies in business. According to Rothschild & Co. (2024), companies implementing Industry 5.0 practices report a 30% to 50% reduction in operational downtime and a 10% to 20% decrease in quality-related costs. Additionally, the Industry 5.0 market was valued at over USD 51.5 billion in 2023 and is projected to grow at a compound annual growth rate (CAGR) of 31.5% between 2024 and 2032 (Global Market Insights, 2024). These statistics emphasize not only the expanding interest in Industry 5.0 but also its measurable value in improving business resilience and sustainability.

Table 1 presents a comparison of key sustainability indicators before and after the implementation of Industry 5.0 practices, based on aggregated data from recent industry reports.

Table 1. Sustainability Impact of Industry 5.0 Practices

Indicator	Pre-Industry 5.0	Post-Industry 5.0	Change (%)
Energy consumption (kWh/unit)	15.2	11.3	-25.7
Material waste (kg/unit)	4.5	2.9	-35.6
Employee satisfaction index	6.4	8.1	+26.6
Product defect rate (%)	3.2	1.9	-40,6

Source: Adapted from industry sustainability reports (2021–2024)

The data in Table 1 highlight the positive sustainability impacts associated with the adoption of Industry 5.0 practices. Notably, energy consumption and material waste show significant reductions, indicating improvements in resource efficiency. Additionally, the increase in employee satisfaction suggests that human-centric approaches contribute positively to workplace well-being. The lower defect rate also reflects enhanced production quality, likely due to better human-machine collaboration and predictive maintenance tools. These results underscore the potential of Industry 5.0 to drive both ecological and organizational performance gains.

3.1. Industry 5.0 as an Enabler of Sustainability

The integration of human-centric design with intelligent automation enables businesses to innovate sustainably. Human-machine co-working environments lead to safer, more inclusive workplaces and promote creativity and problem-solving (Nahavandi, 2019). Technologies like collaborative robots (cobots), digital twins, and AI-driven decision systems contribute to optimizing energy use and minimizing waste.

3.2. Circular Economy Integration and Workforce Transformation

Industry 5.0 supports the circular economy by facilitating the reuse, remanufacture, and recycling of products through precise data collection and predictive maintenance. For instance, digital twins allow for real-time product lifecycle tracking, enabling more efficient resource allocation and reducing environmental impact (Geissdoerfer et al., 2017). A major tenet of Industry 5.0 is valuing human contributions. This approach requires upskilling employees and fostering a culture of continuous learning. Organizations that invest in human capital not only enhance sustainability outcomes but also increase employee satisfaction and retention (Kamble et al., 2020).

3.3. Most Useful Elements of Industry 5.0 for Sustainability

Several technologies and principles within the Industry 5.0 framework have been identified as particularly valuable for promoting sustainability in business operations. Among these, collaborative robots (cobots) enhance worker productivity and safety, reducing accidents and improving process efficiency. Digital twins allow for real-time monitoring of production systems, enabling better decision-making that minimizes waste and optimizes resource use (Ivanov et al., 2020). Moreover, artificial intelligence and machine learning provide predictive analytics that facilitate preventive maintenance, thus extending equipment lifespan and lowering energy consumption (Rajput & Singh, 2019).

In addition, additive manufacturing supports localized production and reduces material usage by enabling just-in-time manufacturing strategies. These elements not only contribute to environmental sustainability but also support economic resilience by reducing reliance on global supply chains. Smart energy systems and IoT-based monitoring further enhance energy efficiency by enabling dynamic load balancing and energy optimization in real-time (Bonilla et al., 2018).

Another significant component is the use of human-digital interfaces and augmented reality (AR) in training and operations, which improves worker engagement and knowledge transfer, further contributing to sustainable workforce development (Madsen & Madsen, 2022). Blockchain technology is also increasingly being explored in Industry 5.0 for ensuring transparency and traceability in supply chains, promoting ethical sourcing and reducing fraud (Saberi et al., 2019).

The integration of these advanced tools within a human-centered design framework allows for comprehensive sustainability gains — environmental, social, and economic — thereby establishing Industry 5.0 as a multifaceted enabler of sustainable business transformation.

4. Discussion

The findings underscore that Industry 5.0 is a holistic approach that requires rethinking traditional business models. Businesses that embrace this new industrial paradigm gain resilience, agility, and sustainability. Key benefits include reduced resource consumption through precision manufacturing, improved stakeholder engagement via transparent and ethical practices, and enhanced brand reputation aligned with ESG benchmarks.

From an operational perspective, Industry 5.0 technologies like AI-powered analytics and real-time monitoring systems allow companies to minimize energy use and waste while maximizing efficiency. These practices lead to not only environmental benefits but also cost savings in the long term. Furthermore, the human-centric focus of Industry 5.0 fosters innovation by encouraging collaboration between employees and intelligent systems, which supports inclusive and participatory corporate cultures.

In terms of competitiveness, Industry 5.0 enables organizations to differentiate themselves in increasingly sustainability-driven markets. The ability to personalize products while maintaining high levels of efficiency allows firms to respond quickly to customer demands and trends, thus gaining market agility. Technologies like digital twins and blockchain enhance traceability and product transparency, which are highly valued by conscious consumers and global partners. Companies that integrate these technologies can build stronger customer loyalty, reduce time-to-market, and improve their adaptive capabilities (Bousdekis et al., 2021).

Moreover, by embedding sustainability into their innovation strategies, businesses can attract impact-focused investors and tap into new market opportunities. This proactive stance not only enhances competitiveness but also future-proofs organizations against regulatory shifts and supply chain disruptions. The integration of advanced digital tools and a motivated, skilled workforce forms a powerful combination that fosters sustained competitive advantage in a rapidly evolving industrial landscape.

Additionally, integrating sustainability into the core of Industry 5.0 strategies can help businesses comply with evolving regulations and market demands. Investors are increasingly prioritizing companies that demonstrate robust sustainability credentials, and Industry 5.0 offers the technological and organizational frameworks to meet these expectations.

However, challenges remain, such as technological investment costs, data privacy concerns, and resistance to change. Future research should explore sector-specific applications and the development of standard metrics for assessing Industry 5.0's sustainability impact.

5. Conclusion

Industry 5.0 represents more than just a technological upgrade—it is a transformative shift that aligns industrial development with human and environmental values. By fostering innovation, enhancing resource efficiency, and empowering workers, Industry 5.0 provides a strategic pathway for businesses to achieve sustainability. Embracing this paradigm is essential for organizations aiming to remain competitive and socially responsible in the long term.

The implementation of Industry 5.0 enables businesses to overcome the limitations of traditional linear production systems by embedding intelligence and adaptability into operations. Through the use of collaborative technologies, companies can better align manufacturing with sustainability goals, from reducing carbon footprints and waste to improving workforce well-being and inclusion. These improvements do not only support environmental and social metrics but also drive operational excellence and long-term profitability.

Incorporating human-centric innovation and ethical digital practices, Industry 5.0 helps organizations address stakeholder expectations, comply with emerging regulatory frameworks, and strengthen their position in increasingly competitive and environmentally conscious markets. It bridges the gap between high-tech advancement and societal values, fostering resilient supply chains, customizable products, and ethical sourcing practices.

Moreover, Industry 5.0's contribution to circular economy principles represents a key differentiator in sustainability-driven transformation. By leveraging real-time data, digital twins, and decentralized ledgers, firms can extend product life cycles, facilitate reuse, and achieve more transparent resource management.

Ultimately, Industry 5.0 challenges organizations to reimagine value creation—not solely in terms of efficiency or output but through sustainable impact, stakeholder inclusion, and systemic innovation. Its successful adoption depends not only on technological readiness but also on visionary leadership and a commitment to integrating human, environmental, and economic considerations into core strategy.

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CLOSING REMARKS

In closing, the papers collected here demonstrate with unmistakable clarity that the future of business administration—particularly in energy-reliant sectors—will be scripted at the intersection of technological acuity, ecological responsibility, and socio-institutional inclusiveness. The empirical evidence marshalled across multiple contexts confirms that competitive ecosystems are evolving toward feedback-rich, data-driven configurations in which circular practices, artificial-intelligence applications, and integrative valuation frameworks continually reinforce one another. This convergence is not merely descriptive; it offers a prescriptive blueprint for scholars and practitioners alike: accelerate the deployment of advanced analytics, embed sustainability metrics as indispensable value drivers, and cultivate organisational cultures that convert diversity and trust into adaptive capacity.

The seminar has underscored that granular data and rigorous quantitative methods can illuminate developmental asymmetries, but their ultimate utility hinges on dialogue across disciplinary, sectoral, and national boundaries. Future research must therefore deepen cross-border comparative designs, refine causal inference in complex systems, and translate analytical insights into policy architectures that scale sustainably. At the same time, enterprise leaders are called to operationalise these findings by integrating ESG criteria into capital budgeting, aligning AI investments with human-centric governance, and forging collaborative networks that extend beyond traditional value chains.

As the global community confronts intertwined challenges of climate volatility, resource scarcity, and technological disruption, the intellectual agenda signposted in these proceedings acquires heightened urgency. It is our conviction that the methodological innovations, theoretical syntheses, and policy-relevant insights presented here will catalyse new waves of inquiry and practice, steering organisations toward resilient, equitable, and low-carbon growth trajectories. May this volume serve not only as a record of scholarly endeavour but also as a springboard for transformative action in the years ahead, inspiring researchers, policy-makers, and business leaders to co-create an economy where innovation and sustainability are indivisible.

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